Lecture Notes in Educational Technology

Stamatios Papadakis
Michail Kalogiannakis *Editors*

# STEM, Robotics, Mobile Apps in Early Childhood and Primary Education

## Technology to Promote Teaching and Learning

Springer

# Lecture Notes in Educational Technology

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# Preface

*STEM, Robotics, Mobile Apps in Early Childhood and Primary Education—Technology to Promote Teaching and Learning.*

The first job of any book editorial ought to be to celebrate the accomplishment of the contributors included here. As readers reading the chapters in this present collection, we invite them to think of the degree of scholarship involved, all directed at thinking about our relationship with technology and young children.

Every collection of papers is fascinating in its way, and this collection is no exception. There are papers from countries as diverse as Greece, Turkey, Germany, Spain, Australia, Cyprus, UK, Finland, USA, Mexico, and Canada.

The topics reflect new issues that demand attention, such as the role of smart screen technologies and digital learning, while including ongoing themes of inquiry and understanding, beliefs, values, and differing models of educational relationship, and the development of inclusive practice. We hope that the reader will find a helpful reference for state of the art in the emerging field of STEM, robotics, and mobile apps on young children learning and developmental outcomes in this research topic.

**Chapter 2**

Erdiller-Yatmaz and Demiral address the role of teachers in transformed learning environments, the challenges teachers experienced during online education, and the windows of opportunities that have come up during this changing process. Their study also reveals various aspects of teachers under unexpected circumstances and put forward new suggestions to integrate technology-based practices in early childhood education by focusing on a significant transformation in today's learning experiences.

**Chapter 3**

Murcia and Cross explore the impact of action research on developing early childhood teachers' confidence, technological knowledge, and ability to generate appropriate pedagogical practices for engaging young children with digital technologies. The authors provide valuable insight into the benefits of teachers working in professional partnerships, taking time for sharing knowledge and experiences, and embedding critical reflection into their planning cycles. In this chapter, learning stories provide evidence that supports the importance of action research for developing teachers' digital capabilities, which are now essential for meeting children's learning needs in a digital era.

**Chapter 4**
Nipyrakis and Stavrou investigate how pre-service teachers' views on technology affect the extent and the nature of technology integration during the design and development of science experiments. From the analysis of pre-service teachers' discussions, it seems that factors related to limited understandings of technology as an inquiry tool, prior experiences with simple instructional materials, and cultural incompatibilities hinder the full potential of technology for science teaching.

**Chapter 5**
Saylan and Kırmızıgül address the preschool and primary school pre-service teachers' experiences about both learning and teaching simulation-based STEM applications. The authors also focus on preschool and primary school students' views on Algodoo-based STEM applications. The authors provide valuable suggestions about engaging pre-service teachers and children in STEM through educational simulations.

**Chapter 6**
Nikolopoulou addresses the supportive and complementary role of digital educational technology (or ICT) in early childhood STEM education. Different skills such as computer programming, mathematical and scientific skills that can be developed via ICT (educational robotics, simulations, models, narrative-rich videos, digital games, etc.), as well as the essential role of the teacher in the early STEM environment, are highlighted.

**Chapter 7**
Tselegkaridis and Sapounidis focus on early childhood and present a systematic literature review on STEM research. The researchers present some significant characteristics of the reviewed studies, such as (a) the number of participants in the intervention, (b) the intervention objectives, (c) the equipment type, and (d) the type of research design. The review showed that many studies in early childhood seem to successfully meet the teaching objectives, although the long-term studies and the quantitative methods are limited.

**Chapter 8**
Chatzigeorgiadou, Hatzigianni, Ratkidou, and Toziou describe a study adopting the design thinking model of IDEO to promote and deepen children's scientific thinking and understanding of the 'water cycle.' A total of 61 children from three Greek kindergartens participated in the study (33 boys and 28 girls), and their mean age was 5.2 years. Teachers' diaries of the activities following the IDEO phases, digital recordings of children's responses, drawings, and concept maps were utilized to document the teaching intervention. The results revealed that the IDEO model was

constructive and contributed to positive learning outcomes. Throughout the intervention, children were active participants, and their scientific knowledge was enhanced. Future research with a design thinking framework exploring science in early childhood education settings is strongly recommended by successfully integrating digital tools.

**Chapter 9**
Kangas, Sormunen, and Korhonen address a little investigated area, young students STEAM education, and introduce invention pedagogy, a Finnish approach to STEAM education. The authors highlight the creative use of technologies through five dimensions and analyze their connections to implemented learning areas in pre-primary and primary students' invention projects. Further, they reveal three orientations to young students' STEAM education, each representing a varying emphasis to the approach and suggesting new directions for further development.

**Chapter 10**
Soberanes-Martín Anabelem addresses a virtual learning environment that contains tools, documents, and other media to support students, tutors, and teachers in early education, including aspects that strengthen the areas of science, technology, engineering, and mathematics (STEM). The author was designed the activities considering the approach of learning by doing. The platform developed from an interdisciplinary perspective supports children's growth and learning from real-world situations.

**Chapter 11**
For the scope of this book, Fislake introduces the history, the current use, and the characteristics of different construction kits up to robotic construction kits. Therefore, he discusses the influences of technical toys on the way young children behave, think, and act in general and how they promote STEM early. He also reports long-term teaching experiences and the current educational use of construction kits in selected learning scenarios against the background of available research results.

**Chapter 12**
Álvarez-Herrero, Martinez-Roig, and Urrea-Solano, in their chapter, present an example of the taxonomy of the most common floor robots that are used to work from a STEM perspective with early childhood education students. This analysis considers the physical characteristics of robots and their possibilities to develop skills and competencies among students. It also lays the foundation for establishing a set of fundamental principles that provide early childhood education teachers with a guide for their choice and, in turn, serve as approaches in any STEM intervention.

**Chapter 13**
Tzagkaraki, Papadakis, and Kalogiannakis present the results of their quantitative research on Greek primary school teachers' attitudes on the use of robotics in the classroom. As mentioned, their attitudes are positive for the application of robotics.

Most participants recognize robotics as a facilitating, valuable, and practical tool for teaching and learning. Also, believe that it contributes to the development of skills. Remarkable is that robotics is recognized as a problematic field to learn and apply.

**Chapter 14**
Sivenas and Koutromanos investigate pre-service and in-service teachers' perceptions on the use of drones in teaching. Using variables from the Theory of Planned Behavior, the researchers investigated attitudes, intentions, and beliefs and compared the two teacher groups. Results indicated a positive correlation between attitudes and intention, while the comparison between the teacher groups revealed that pre-service teachers had stronger intentions and more positive attitudes, behavioral beliefs, and perceptions than in-service teachers. The researchers also highlight several implications and recommendations for the future use of drones in teaching.

**Chapter 15**
Falloon reports results from a study involving 45 six-year-olds completing a series of coding challenges working in three different pairings. The study used an adaptation of Mercer's (1994) Talk-Type and Hennessy et al.'s (2016) Classroom Dialogue analytical frameworks to evaluate the quality of oral discourse between the students and determine the different groupings had on learning progress and knowledge-building. Results suggested benefits from self-select methods, with students displaying higher task engagement, relational trust, and learning interdependence. These results are of high significance to early years' educators using grouping to improve students' learning.

**Chapter 16**
McGregor, Fordsham, and Bird discuss and illustrate how tablet technology supports inquiry learning within STEM contexts. Their focus on how digital technology can promote scientific practices highlights how teachers and learners perceive its use differently. A sociocultural perspective of learning was adopted to examine the juxtaposed ways that teachers and learners acknowledge digital affordances. In the absence of agreement about the effective use of digital devices for learning, this chapter offers a theorization about the ways that affordances or opportunities for young learners should be noted and pedagogically promoted in science inquiry situations.

**Chapter 17**
Ulutas et al., in their chapter, highlighted that digital stories are very functional to support rich content in math education. Researchers conducted a study to evaluate early childhood teachers' achievements after receiving digital storytelling training. At the end of the week-long theoretical and practical training with 30 teachers, they found that the teachers experienced increased self-confidence, were motivated toward creativity and production, and demonstrated an enhanced ability to integrate mathematics and technology.

**Chapter 18**
In their chapter drawing upon Vygotsky's notions of the zone of proximal development (ZPD), tools, and mediation, Li and Taber provide a new perspective by exploring the potential use of AR applications (apps), holography, and AI-based tools in early childhood science education. The key argument is that these tools can potentially change the nature of the interaction between learners and learning materials, and they offer significant affordances in early childhood science education. The mission of the present chapter is to inform the design and development of educational technology based on psychological and pedagogical perspectives and help parents and early childhood teachers understand the potential use of AR, holography, and AI in science education.

**Chapter 19**
In their chapter, Schwab-Cartas, Caldairou-Bessette, and Mitchell offer reflexive accounts of working with young children to produce cellphilms. They outline how researchers, teachers, and other tutoring adults can use cellphilming as a participatory visual method to support young children to express themselves on matters that concern them. The authors also propose cellphilming as providing opportunities for ethics education with young children on mobile devices and the Internet.

**Chapter 20**
Polat Hopcan et al. design, develop, and test the usability of a mobile game for primary school students in mathematics education. For this purpose, a 2D mobile game was developed with Unity and usability tests and conducted with primary school students. This study will develop digital educational games by suggesting ideas for reducing usability problems.

**Chapter 21**
Gözüm, in his chapter, examined the mediation strategies of parents who play digital games with STEM content with their children and the educational content of STEM content of digital games. The study determined that parents used the active co-playing strategy to use STEM-content digital games to teach their children.

**Chapter 22**
Aranda, Campbell, Ferguson, and Speldewinde focus on describing their research in preschool settings where educators introduced digital technologies (in the form of Beebots) to their children using a direct and surrogate embodiment. Their research questioned how Beebots and robotic devices could support and complement children's learning in STEM. The researchers followed the educators' practices as they introduced children to digital technologies and continued scaffolding the learning. As they explored children's interactions with the Beebots and the educators, they considered the intersections of play, pedagogy, and learning through embodiment.

**Chapter 23**
Papadakis, Gözüm Kalogiannakis, and Kandır, in their chapter, examined parent mediation strategies for the digital games played by preschool children during the

pandemic process by comparing Turkey and Greece. Researchers also examined the effects of parents who play and do not play digital games with their children during the pandemic on mediation strategies by country. In the research, suggestions were made about the mediation strategies used by Turkish and Greek parents.

**Chapter 24**

Kye discusses the process of applying theory to practice in a family engagement program grounded in a culturally responsive framework. The preschool program is discussed in current issues and approaches concerning early childhood STEM education equity. The author highlights guiding principles and practices for teacher educators and classroom teachers who seek to apply equity frameworks in their STEM teaching.

**Chapter 25**

Ampartzaki, Kalogiannakis, Papadakis, and Giannakou present the results of a survey conducted to explore the opinions of teachers, student-teachers, parents, artists, and STEM professionals. In summary, the results showed that: (a) although teachers, student-teachers, and STEAM professionals knew about the STEAM approach, only a few had the experience of implementing it; (b) the major difficulties educators faced in implementing STEAM relate to understanding the methodological principles of this approach and the lack of educational resources; (c) educators had received limited support by policymakers, advisers, etc.; (d) STEAM was expected to enrich the curriculum with hands-on and active learning and have a positive impact on children's critical thinking and communication skills, as well as their overall development; (e) STEAM is expected to increase the motivation and participation of girls and disadvantaged students; and (f) educators and parents recognize the vulnerability of disadvantaged students, but do not seem to be aware of female underachievement in STEM subjects and careers.

Rethymnon, Greece

Stamatios Papadakis
Michail Kalogiannakis

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# Contents

# About the Editors

**Stamatios Papadakis** has been a postdoctoral researcher in educational technology, with emphasis on mobile learning, at the Department of Preschool Education at the University of Crete, Greece, since 2016. He has worked as an adjunct Lecturer in Education teaching Didactics in Programming (2017–2018) at the Department of Computer Sciences, School of Sciences and Engineering at the University of Crete, Greece. Since 2017 he has worked as an adjunct Lecturer in Education teaching Informatics (2017–2018) at the Department of Preschool Education, School of Education, University of Crete, Greece. His scientific and research interests include the study of mobile learning, especially on the use of smart mobile devices and their accompanying mobile applications (apps) in preschool and primary education, focusing on the development of computational thinking and students' understanding of numbers. Furthermore, he currently investigates how a STEM learning approach influences learning achievement through a context-aware mobile learning environment in the preschool classroom and explain the effects on preschoolers' learning outcomes.

**Michail Kalogiannakis** is an Associate Professor of the Department of Preschool Education, University of Crete, and an Associate Tutor at the School of Humanities at the Hellenic Open University. He graduated from the Physics Department of the University of Crete and continued his post-graduate studies at the University Paris 7-Denis Diderot (D.E.A. in Didactic of Physics), University Paris 5-René Descartes-Sorbonne (D.E.A. in Science Education) and received his Ph.D. degree at the University Paris 5-René Descartes-Sorbonne (Ph.D. in Science Education). His research interests include science education in early childhood, science teaching and learning, e-learning, the use of ICT in science education, distant and adult education, and mobile learning. He has published over 120 articles in international conferences and journals and has served on the program committees of numerous international conferences.

# Chapter 1
# Introduction

**Stamatios Papadakis and Michail Kalogiannakis**

**Abstract** As the days of mimeograph machines and chalkboards have long passed, authorities in all civilized countries acknowledge the need to equip all citizens with the necessary competencies to use digital technologies critically and creatively. According to the twenty-first-century skills framework, digital literacy is an essential skill for students of all ages to develop. The ability to be a creator rather than just a consumer of technology is increasingly seen as an essential skill to participate fully in a digital society. The ability to encode and understand code is becoming more and more a fundamental skill to master to participate actively in our digital society and economy. Hence, its integration throughout all educational levels and the early ages is considered valuable. Evidence shows that even children as young as four can engage in core computational thinking skills, provided they work with a developmentally appropriate tool that supports such learning.

As the days of mimeograph machines and chalkboards have long passed (Machado & Tao, 2007), authorities in all civilized countries acknowledge the need to equip all citizens with the necessary competencies to use digital technologies critically and creatively (Redecker, 2017). According to the twenty-first-century skills framework, digital literacy is an essential skill for students of all ages to develop. The ability to be a creator rather than just a consumer of technology is increasingly seen as an essential skill to participate fully in a digital society (Sáez-López et al., 2016). The ability to encode and understand code is becoming more and more a fundamental skill to master to participate actively in our digital society and economy (European Schoolnet, 2021). As Wing (2006) states, "to reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability" (p. 33). Hence,

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its integration throughout all educational levels and the early ages is considered valuable. Evidence shows that even children as young as four can engage in core computational thinking skills, provided they work with a developmentally appropriate tool that supports such learning (Strawhacker et al., 2018).

Apart from that, the current generation of 'digital natives' is growing in a digitized world. Technology is evolving rapidly, creating new fields of study, new forms of employment, and new skills and abilities (Yang et al., 2015). Despite the fact of the initial concern about the use of technology in the education of young children (Cordes & Miller, 2000), proof of the benefits of using developmentally appropriate interactive technology has been well documented (Vaiopoulou et al., 2021). In recent years, the rapid development of technology has contributed to the development of new educational tools (Poultsakis et al., 2021). Furthermore, access to mobile applications (apps) and smart mobile devices such as tablets continuously increases worldwide. These tools are becoming cheaper and more easily accessible.

Meanwhile, research indicates that educators and parents accept smart screen technologies as sources for educational renewal and learning opportunities for children ages 3–6 (Papadakis et al., Papadakis, Alexandraki, et al., 2021). The vast dissemination of various forms of ICT (Information and Communications Technologies) has led students to the gradual conquest of functional knowledge that facilitates the development of higher levels of practical skills useful in STEM education (Science, Technology, Engineering, and Mathematics) or STEAM (Arts) that applies to real-life contexts. As Wing (2006) states, this knowledge, referred to as computational thinking, builds on the power and limits of computing processes, giving students the necessary methodology and models to solve problems and design systems.

Research demonstrates that early exposure in STEM and CT fields contributes to developing significant cognitive outcomes and critical skills, such as executive functioning and fluid reasoning, leading to later school success (Bustamante et al., 2020). Robots and robotics kits effectively introduce CT, STEM, STEAM, coding, and twenty-first century skills to young students. These tools are often combined with mobile applications (apps) that utilize a smart mobile device (Papadakis, 2021), offering real practical experiences to the students. At the same time, hands-on robotic activities and tasks—due to their play aspect- are fun and attractive for them (Atmatzidou & Demetriadis, 2016). Additionally, research supports that the preschool classroom environment is rich in connections and opportunities to engage actively in STEM and STEAM activities (MacDonald et al., 2020). Nowadays, there are numerous educational tools available for young-age children to engage them in STEM activities such as visual block-based environments (e.g., ScratchJr), online environments (e.g., Code.org), robotic devices (e.g., Bee-bot, Makey-Makey), and unplugged activities (Sullivan et al., 2017).

There is also a close relationship between educators' knowledge, views, and attitudes towards technology and how to adopt technology in early childhood classrooms (Papadakis et al., Papadakis, Vaiopoulou, et al., 2021). Teachers' perceptions, attitudes, and technological competencies are the primary determinants of technology adoption in curriculum and pedagogy. Teachers themselves often have no formal education in computing, and they cannot communicate their students' enthusiasm or understanding about what happens inside a computer to make it work. Since the combination of robotic kits and related apps can make the instruction more exciting, teachers must be trained and supported to use these digital media effectively (Chan, 2020).

Nevertheless, the effective integration and use of educational technologies into preschool education remain a significant issue (Vidal-Hall et al., 2020). As preschool teachers play a critical role in digital technology integration in early childhood education (Tzagkaraki et al., 2021), teachers need to acknowledge digital media necessity. In the published literature, it has been found that teachers' attitudes to digital technologies affect the use of technology in educational practices. Thus, teachers must realize a clear benefit of using educational technology to promote STEM learning to change their teaching behavior effectively. Teachers need to understand emerging technology to incorporate these modalities into their classrooms (Chan, 2020). This follows Vidal-Hall et al.'s (2020) findings, which showed that any attempt to integrate digital technologies effectively is needed to consider the teacher's pedagogical beliefs and practice.

## References

Atmatzidou, S., & Demetriadis, S. (2016). Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences. *Robotics and Autonomous Systems, 75*, 661–670.

Bustamante, A. S., Schlesinger, M., Begolli, K. N., Golinkoff, R. M., Shahidi, N., Zonji, S., Evans, N., & Hirsh-Pasek, K. (2020). More than just a game: Transforming social interaction and STEM play with Parkopolis. *Developmental psychology*, *56*(6), 1041.

Chan, K. K. (2020). Using tangible objects in early childhood classrooms: A study of Macau pre-service teachers. *Early Childhood Education Journal, 48*, 441–450.

Cordes, C., & Miller, E. (2000). *Fools' gold: A critical look at computers in childhood*. Alliance for Childhood.

European Schoolnet. (2021). European Schoolnet's 2020 Annual Report, Brussels, Belgium. http://www.eun.org/documents/411753/1866395/EUN+Annual+Report+2020+%28Web%29.pdf/01bd3803-dc1d-4518-bfa6-00456c68f71e

MacDonald, A., Huser, C., Sikder, S., & Danaia, L. (2020). Effective early childhood STEM education: Findings from the Little Scientists evaluation. *Early Childhood Education Journal, 48*(3), 353–363.

Machado, M., & Tao, E. (2007). Blackboard vs. Moodle: Comparing user experience of learning management systems. In *37th Annual Frontiers in Education Conference-Global Engineering: Knowledge Without Borders, Opportunities Without Passports* (FIE'07) (p. S4J-7). IEEE.

Papadakis, S. (2021). The impact of coding apps on young children Computational Thinking and coding skills. A literature review. *Frontiers in Education*, **6**, 657895. https://doi.org/10.3389/feduc.2021.657895

Papadakis, S., Alexandraki, F., & Zaranis, N. (2021). Mobile device use among preschool-aged children in Greece. *Education and Information Technologies*, 1–34. https://doi.org/10.1007/s10639-021-10718-6

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences, 11*(5), 204.

Poultsakis, S., Papadakis, S., Kalogiannakis, M., & Psycharis, S. (2021). The management of digital learning objects of natural sciences and digital experiment simulation tools by teachers. *Advances in Mobile Learning Educational Research, 1*(2), 58–71.
Redecker, C. (2017). *European framework for the digital competence of educators: DigCompEdu.* In Punie, Y. (ed). EUR 28775 EN. Publications Office of the European Union, Luxembourg.
Sáez-López, J. M., Román-González, M., & Vázquez-Cano, E. (2016). Visual programming languages integrated across the curriculum in elementary school: A two year case study using "Scratch" in five schools. *Computers & Education*, *97*, 129–141.
Strawhacker, A., Lee, M., & Bers, M. U. (2018). Teaching tools, teachers' rules: Exploring the impact of teaching styles on young children's programming knowledge in ScratchJr. *International Journal of Technology and Design Education, 28*(2), 347–376.
Sullivan, A. A., Bers, M. U., & Mihm, C. (2017). *Imagining, playing, and coding with KIBO: Using robotics to foster computational thinking in young children* (p. 110). Siu-cheung KONG The Education University of Hong Kong.
Tzagkaraki, E., Papadakis, S., & Kalogiannakis, M. (2021). Exploring the use of educational robotics in primary school and its possible place in the curricula. In *Educational Robotics International Conference* (pp. 216–229). Springer, Cham.
Vaiopoulou, J., Papadakis, S., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Parents' Perceptions of educational apps use for kindergarten children: Development and validation of a new instrument (PEAU-p) and exploration of parents' profiles. *Behavioral Sciences, 11*(6), 82.
Vidal-Hall, C., Flewitt, R., & Wyse, D. (2020). Early childhood practitioner beliefs about digital media: Integrating technology into a child-centred classroom environment. *European Early Childhood Education Research Journal, 28*(2), 167–181.
Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35.
Yang, T. C., Hwang, G. J., Yang, S. J., & Hwang, G. H. (2015). A two-tier test-based approach to improving students' computer-programming skills in a web-based learning environment. *Journal of Educational Technology & Society, 18*(1), 198–210.

# Part I
# Early Childhood and Primary Education Teachers

# Chapter 2
# Building from Scratch: Online Education Experiences of Early Childhood Education Teachers in Turkey

**Zeynep Erdiller Yatmaz and Seran Demiral**

**Abstract** The present study, initiated in March 2020 with the onset of the COVID-19 pandemic, aims to understand the online education experiences of a group of early childhood teachers in Turkey and how the "new way" of early childhood education was actualized from teachers' perspectives. Data gathered through in-depth interviews via videoconference platform due to health and safety restrictions conducted with teachers working in private early childhood education institutions, which provide online education for children between 3 and 6 years. The study tried to find answers to the following research questions: "What is the role of teachers during the COVID-19 pandemic at schools, in transformed learning environments and in the lives of families?" "How did the teachers transform their physical learning environments (classrooms) into online learning environments?" "What kind of challenges and windows of opportunities did teachers experience during online education?" We focused on the major transformation in the learning experiences in early childhood education today by considering the technology-enhanced learning and the nuances between online and face-to-face education. Our study revealed various aspects of teachers under unexpected circumstances and put forward new suggestions to integrate technology-based practices in early childhood education within the frame of teachers' changing roles and responsibilities.

**Keywords** Online education · Teachers' agency · Early childhood education · Technology-enhanced learning

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## 2.1 An Unexpected Transformation in Education Practice

While COVID-19 transformed the education practices at all levels, both every day and educational activities of early childhood education teachers, young children and caregivers have differentiated quite a lot. Yet, how children and families have been experiencing the pandemic has been among the most discussed and analysed issues since the onset of COVID-19 (Ex: Başaran & Aksoy, 2020; Yıldız & Bektaş, 2021; Yıldırım & Bozak, 2021; Karahan et al., 2021). Availability and accessibility of online education practices to the general population of children have been among the major concerns of educators, families and non-governmental organizations in Turkey (ex: Children's Accessibility to their Rights During Covid-19 Pandemic).

Resembling the influences of former drastic changes on children's development through the social and economic conditions (Bjorklund, 2012: 93) the situation of a pandemic caused a tremendous gap between different groups within economic, national and social levels (SDGG, 2021; Tarlabaşı Toplum Merkezi, 2020). As a matter of fact, educational inequalities have become more visible because online education was not accessible for many children during compulsory distance education, not to speak of the availability of the quality of online education. Lack of preparation for such a dramatic change in educational practices and uncertainty about the duration of online education, placed a heavy burden on teachers, families and children, even for a privileged group of children, who had gained access to online education one week after the lockdown. There were many challenges because both teachers and school administrators had no preparation for such adaptation.

This chapter aims to reveal how changes occurred within these specific online classroom environments through teachers' perspectives. Even though the teachers who participated in the study consist of a very small group given the population, we believe that every experience is loaded with significant potential for understanding and enriching current and further practices while facing a once-in-a-century event, like a pandemic. While struggling with health and safety crises surrounding themselves and their families, early childhood education teachers had to deal with constructing online early childhood education practices from scratch, particularly in Turkey. When the lockdown was in effect and after the first couple of days, all the attention focused on schools, and hence, on teachers, for an effort to meet the needs of young children and to offer them a sort of "normality." This pressure was more evident for teachers who were working in private schools; and they were among the first group of teachers who began to implement the new form of education in their digital classroom environments almost one week after the lockdown in Turkey. As challenging as it might seem at that time, it was also assuring to be witnesses of their adaptation and resilience for many people, including parents, children and administrators.

Through this research, we wanted to listen to those teachers, whose voices could not be heard by many at that time, to understand and vocalise their experiences, feelings, gains and challenges. We aimed to understand the teachers' perceptions about the new education process they were experiencing; therefore, we listened to their interpretations of the nuances between online and distance/remote education. Much different from a regular online education experience, in which the content and stages are well-designed from the beginning, the lockdown as an unexpected situation suddenly changed the education practices. Because the school closures forced teachers to adapt the education process from the existing physical spaces into an online environment, ORL [Online Remote Learning], as the combination of traditional remote education and online learning practices based on technological developments, has become a widespread conceptualization (Mourlam et al., 2020). In times of the pandemic and during the school closure process, ORL and such approaches have become an essential debate to find out a new way. Since distance learning requires an adaptation of traditional education; it became the proper concept for our study. Online education and distance/remote learning both include conceptual differences and offer distinctive experiences. However, we prefer using "online" and "distance" notions interchangeably based on teachers' referrals to not being able to share the same place and the requirement of technology to address technology-enhanced approaches. Hence, we aim to step forward to get beyond the current circumstances and reconsider online early childhood education practices in an expanded frame.

Driving research questions of the study are as follows:

- What is the role of the teacher during the COVID-19 pandemic at schools in transformed learning environments and the lives of families?
- How did the teachers transform their physical learning environments (classrooms) into online learning environments?
- What kind of challenges and windows of opportunities did teachers experience during online education?

The first research question would give us a perspective of "teacher's agency in online education." As we conducted our research between June and September in 2020, we had the chance to observe how teachers' roles have changed during the transformation of the existing early education practices into online environments both in terms of educational practices and their everyday lives. With the second question, we aimed to understand how teachers conduct their agency while transforming their experiences into online learning environments. Given that all of the teachers were accustomed to physically face-to-face, group-based teaching practices within a physically shared learning environment, interacting with children from a screen, where everyone is located in a different place, has been an initial shock for all of them, let alone being a challenge. The third question enabled us to realize the struggles and window of opportunities that online early childhood education brought into the field of early education.

In this chapter, we will first discuss how technology-enhanced learning can occur in early childhood education. Secondly, we will introduce the case study we conducted with early childhood teachers working in private preschools in Istanbul about their online education experiences due to the COVID-19 pandemic. Thirdly, we will elaborate on the research findings that revealed a major transformation in the learning experiences provided to young children besides the new technology-based learning environments. Lastly, we will try to conceptualize teachers' agency during the entire process by particularly focusing on their roles, responsibilities, challenges and windows of opportunities.

## 2.2 Technology-Enhanced Learning in Early Childhood Education

The online environment has many difficulties for teachers, parents, and especially children because adapting traditional classroom practices into the online environment might be more challenging for young children. All educators need to "develop a supportive and authentic relationship with the child" (Blum & Parette, 2015: 167) in both physical and online environments. Creating an inclusive classroom environment is already a tough issue because of children's development patterns and diversity (Palincsar et al., 1993). Considering that in early childhood education, both the relationships among children and the teacher-student interaction have more critical significance than those of other educational levels, distance education might be more challenging for early childhood teachers compared to others. For an online classroom, established immediately in the middle of a health crisis, there have been more difficulties for sure. Ranging from the levels of competency in technology to tendencies for online interaction of each individual; there are many critical factors to provide a safe, supportive, effective classroom environment. As building a learning community (Palloff & Pratt, 2001) should be one of the fundamental purposes in face-to-face education, the question here is how to transform the existing practices into a new space for both teachers and children.

Children under six years old are ready for literacy, a fundamental stage for cognitive development, and at the peak of developing social skills through group activities in a shared public place through peer-to-peer communication. In the early childhood education field, there are contradictory views about children's interaction with technological devices. On the one hand, digital devices seem like an obstacle for conducting a community where teachers and children could effortlessly be involved in a traditional classroom environment; on the other hand, competency in digital environments may become a necessary skill for the younger generations in the twenty-first century. For instance, coding education in early childhood is more than technical skills; it is indispensable for self-expression and communication skills anymore (Papadakis, 2021). While even the youngest children must develop their digital literacy skills by adapting to new educational practices, families can also support the technological abilities of children (Saracho, 2015: 201). Young children have been communicating through online platforms and experiencing technological interactivity for a very long time indeed. Early STEM learning would also provide new models for education, ready access for teaching activities, and may engage children using technology for their collaboration (Pasnik & Hupert, 2016).

Young children can construct both group interaction and hands-on activities through educational robotics (Papadakis, 2020); on the other hand, hands-on learning may also go further by integrating a digital literacy environment with supports of parents and caregivers (Pasnik & Hupert, 2016). However, digital environments do not seem capable enough to encounter others in-person to share, to extend knowledge (Plowman & McPake, 2013). In early childhood education, hands-on learning, project-based learning, learning by group activities and constructing a community of learners are commonly acknowledged mediums for learning and development. This brings out the essential questions such as, how can teachers provide a learning process without sharing the same environment, or how can children experience their physical and social-emotional community? Is it possible to support the social and emotional development of young children from a specific distance? To respond to these questions, it seems significant to indicate that screens of computers or other digital devices compound various spatial experiences. As a result of this, children can share a common (virtual) space, but "designing, building, and problem-solving can happen beyond the computer screen" as Umaschi Bers (2007: 15) recalls. Distance education practices reveal that virtual spaces proceed a common but differentiated learning environment through online media platforms. Due to the lockdown process, distance education becomes the usual learning activity, which reminds us that some theorists argue "adaptable learning" within technology-enhanced prospects (Havard et al., 2016).

Early childhood teachers ought to engage children in digital learning environments by implementing safety practices in online spaces and considering children's well-being, as digital footprints are formed in the period of early childhood, even as early as in the period of infancy (Edwards et al., 2016: 43). Technological competency is becoming the necessity of the digital era that we have been experiencing. Even younger children need to cope with virtual reality to become empowered. Consequently, early childhood settings need to be constructed by taking into consideration both technological contexts and the social and cultural context of young children. Widespread knowledge and new ideas have always been essential for the early childhood education field since early years constitute the fundamental basis for younger generations' integration within the existing society. Selwyn (2012: 219) underlines the necessity of questioning how digital technologies can produce social relations and how they might improve learning. Here we encounter two significant issues to touch upon: the first is the possibility of adapting the traditional settings for early childhood education into digital environments by investigating whether it is unavoidable or not. The second is how much possible to support children's social and psychological development within online education settings.

Taking into account the first, Personal Digital Assistants (PDAs) as mobile digital devices and educational applications constitute examples: educational settings are established upon mobile applications. According to Papadakis and Kalogiannakis (2020), most educational apps cannot support cognitive development in early childhood adequately because the majority of apps that are accessible in digital stores target academic skills in particular. The unique nature of early childhood education requires more than developing academic skills as we will discuss regarding the teachers' commentaries while revealing the ways of establishing a community through online classroom experiences. That discussion would lead us to consider the second aspect, which includes emotional and social trajectories of online educational settings. In both formal and informal learning environments, educational apps should be efficient to provide children's cognitive development and support their social and emotional environment. Hence, through a few aspects as usability, efficiency, parental control and security, the Evaluation Tool for Educational Apps (E.T.E.A) have been developed to enhance (Papadakis et al., 2020).

Computational Thinking (CT) is another concept improved upon in Papert's approach (Angeli & Giannakos, 2019; Papadakis, 2021; Umaschi Bers, 2020). To improve CT education for children, teachers also need to learn how to design such activities and know using CT learning technologies (Papadakis, 2021); therefore, teachers' digital literacy also becomes a significant indicator in early childhood education. Because CT is beneficial not only for the problem-solving of younger children but also for social interaction (Umaschi Bers, 2020), children's cognitive, emotional and social development might depend on technology-enhanced learning. To provide peer-to-peer learning through interaction with technology is here an essential debate (Saracho, 2015: 191). At this point, appropriate use of technology afforded various trajectories in knowledge production according to children's tendencies. Turkle and Papert (1991: 14) underlined the interaction of children with the machines. Through their analyses of children's perceptions about computers, they addressed that children consider those non-living things as persons if they have relations. They also compared children's behaviours towards virtual objects they saw on the screen with concrete things they touched in real life. Digital environments offer children ways to explore, combine, gain knowledge and transform various (learning) activities, while effective instruments also help young children to expand their visual experiences.

Children's interaction with touch-screen technologies is a widespread topic in recent years (Edwards, 2019; McLean & Edwards, 2016), and family environments also affect the levels of communication through digital technologies. Digital applications support various educational areas, such as learning, activity structure, narrative and language, even social interaction (Joanna et al., 2021). Online education brings different places together through the virtual space that the meanings of technology-enhanced learning also changed. Different spatial experiences reveal children's tendencies of graphic and written communication by indicating screen-based activities and texting (McPake et al., 2013) Within such distinctions, creative content is always an essential matter to conduct a collaborative educational environment. Educational technology research is improved by adaptable settings, whereas the experiences of young children are harder to analyse. Since young children learn social roles and peer-relations through participating in an interactive community, digital technologies ought to provide pedagogical approaches through supportive activities (McPake et al., 2013).

Teachers can arrange cooperative and collaborative learning environments through some exercises to support a reciprocal relationship among children. To conduct such connections that teachers may use, as Umaschi Bers (2007: 33) takes attention to, six C's to enrich learning environments by "competence, confidence, caring, connection, character, contribution." Almost all of them require relation and belonging to a community, which makes it more challenging for an online learning environment to meet those requirements. Furthermore, she highlights (2007: 38) the impacts of communication and collaboration on creating a technologically enhanced learning environment. Technological development enriches children's learning aspects, whereas a physical connection should support the other C's. Although it is possible to achieve confidence and character at individual levels by utilising an effective online connection and digital competency, children cannot experience care and contribution without peer relationships. Sociocultural perspectives may execute different aspects at this point because "cooperative learning often produces better performance than individual learning does" (Bjorklund, 2012: 98).

The social and cultural worlds of children play a significant role in children's development (Edwards et al., 2016: 39). They construct knowledge through the collective experiences in early childhood with peers and adults around them. It is remarkable to understand how young children generate their knowledge utilising online experiences, on the other hand. They generally construct social, emotional, and cognitive skills within a shared space in collaboration. The efficient uses of online education do not depend on technological competency, however. Technology-enhanced learning can be successful if only teachers and children both accomplish interaction within a collaborative environment. Therefore, the critical aspect of technology-enhanced education is not the technology itself but the pedagogy (Palloff & Pratt, 2001: 153), or how we combine the two. Even if teachers can supply a constructionist learning environment for each child, it must be extremely challenging to continue online education for the long term.

With this study, we attempted to discuss recent online education experiences of early childhood education teachers within the frame of technology-enhanced learning, an ongoing debate for different levels. Through the sociocultural theory perspective, active participation and cultural components constitute the fundamental needs for early ages (Edwards, 2009: 37), so, we question how teachers found ways to provide cooperation and collaboration that would stay as basic skills and the extent of it. In the other aspects, integration with digital environments becomes compulsory to achieve. Furthermore, exact participation is critical for children to take part in "the world around them now and in the future" (Burnett & Daniels, 2016: 20). We aimed to focus on manifold faces of early childhood education through teachers' perspectives in order to understand future aspects of technology-enhanced learning regarding potentials and pitfalls in online education experiences, hence future pedagogies might reveal.

## 2.3 A Case Study with a Group of Early Childhood Teachers in Istanbul

### *2.3.1 Participants of the Study*

Teachers from four different early childhood institutions located in Istanbul participated in the study. While three out of four institutions were run by executive boards consisting of professionals, and parents have no direct involvement in the decision-making process aside from parent-school cooperation; in the other institution, parents' contribution in the decision-making process is a significant component of the institution's administrative processes. Moreover, while the three institutions target families from the highest SES level in Turkey, with an average tuition of 95,000 TL (approximately 13,000 USD, where the minimum wage is 382 USD a month) a year, the fourth institution targets families from relatively lower SES compared to the other three.

Within the educational philosophies of the institutions, students are placed at the centre of learning, and the teacher's role in the educational process is defined as guiding students' learning instead of functioning as a source of information. Offering a variety of learning experiences tailored according to individual differences of children and targeting the present and upcoming needs of the twenty-first century is among the highly emphasized goals of all four institutions.

In this study, ten out of eleven participants were working with 4 and 5-year-olds, and only one participant was working with 3-year-olds. The average age of the participants is 32. In terms of family demographics, eight participants were married, seven participants did not have children, and four participants had at least one child. Ten out of eleven participants of the study were female early childhood education teachers. Although we would like to interview male and female teachers, we could interview only one male participant; hence, we could not integrate any gender perspective for this study. It may also signify that there is a huge gender gap among teachers, especially in early childhood education. Occupational preferences upon gender and how gender roles impact early childhood teaching experiences might be interesting topics for further studies.

Because online education brings public and private spaces, including families of children and households of teachers together, the possible impact of flexibility in working hours and changed perceptions of time, space or private spaces on teachers' responsibilities and roles were also worth exploring. However, we did not discuss those in this chapter, as it was beyond our scope.

### *2.3.2 Methodology*

Online education, initiated as a necessity of the pandemic situation has prompted many research studies, both quantitative and qualitative methodologies in multiple disciplines. In this study, conducted with early childhood teachers, we tried to focus on the experience itself and on the changing perceptions in the face of changing learning environments. Hence, we aimed to reveal current early childhood education experiences through in-service teachers' points of view and make their voices heard. To understand in-service teachers' online practices and to give them a voice for sharing their positive and negative feedback about the online education process, we utilized "adaptive theory," developed by Layder (1990) from "grounded theory." Glaser and Strauss (1967) used that approach to generate new theories according to reality, based on everyday practices in fieldwork. In grounded theory, researchers begin to study by admitting they need to behave as 'tabula rasa.' Whereas, Layder (2013) explains that researchers can enrich empirical data with explanatory assumptions by providing pre-existing theories to examine.

The essential principles of this method are designated as:

- In the process of selective coding, fundamental categories emerge, even after codes are reduced and several categories are determined; pre-coding and selective coding would continue simultaneously during the content analysis of the research
- The notions emerging in the coding process interact with pre-existing theories; hence livable and constantly developing theory may exist according to conceptualising the social world (Layder, 2013: 102)

For early childhood education, the pre-existing theory is the usual classroom environment where children come together and learn by hands-on experiences, experimenting and interacting with the physical and social environment. At that point, our goal is to try to understand whether children can constitute a peer culture in the virtual environment and whether they experience online spaces as a virtual classroom or not. An online learning environment exists so that children can learn everything in the 'curriculum,' which had less importance before distance education experiences in early childhood education. According to the participants, the essential purpose of online education was to provide an everyday routine for children in the beginning. On the one hand, the adaptive theory seems convenient because all interviews are conducted through online platforms. We, as researchers, experienced face-to-face communication within the perception of online spaces as shared environments, and the fieldwork process itself was adaptive through a self-reflexive perspective. On the other hand, the teacher's agency and their active roles in early childhood education used to be limited by face-to-face interaction before their adapted practices. Instead of admitting online spaces as "non-place," where participants would lack connection, collaboration and communication, the adaptive theory may also become a tool to construct a new theory regarding digital space as the new learning environment.

## 2.4 Findings and Discussion

We initiated the study a few months after the lockdown while many things were still in process. Hence, we saw that the interactive questioning itself, carried on for data collection, provoked teachers to question their practices and roles and engage in self-criticism about their collective and individual experiences since the pandemic suddenly broke out in their personal and professional lives. We asked our participants how the new form of early childhood education is constructed, what kind of sources they utilised, whether they adapted themselves and their pre-existing practices to online environments, or whether they had to create something new only for the newly constructed learning environment. Therefore, the teacher's roles in shaping and creating a new learning environment and their agency have become a remarkable area of exploration in the study. The teachers' contribution in the online early childhood education practices of their schools, how they manage the demands of parents and administrators, what type of difficulties they faced, and how they found solutions against their challenges have become the focus of exploration. As discussed while describing the case, the participants constitute a homogeneous teacher group who graduated from prestigious universities in Turkey and worked in private institutions targeting economically and socially privileged parents. Even though the focus of the study was not parents particularly, it is necessary to indicate that children and their caregivers are also a homogenous group at economic, social and cultural levels.

### *2.4.1 Facing the "New Way" of Early Childhood Education*

With the onset worldwide, teachers, children and families found themselves facing a new kind of phenomenon in education, and people began to use different terms to define the same phenomena. Online education and distance/remote education are the terms that are commonly used among teachers, parents, administrators and decision-makers. Therefore, we asked teachers about how they refer to the new teaching and learning experiences they provide for young children and whether they differentiate between online education and distance education or not. Most teachers separated the two notions of online and remote education instead of using ORL. But some of them stated that they were not sure about the essential difference. Moreover, teachers generally stated that they preferred to use the term online meetings with children as they believed that it was what they were doing initially.

The rationale for using the term online education to describe the education practices following the pandemic was the existence of interaction between teachers and children and lack of preparation regarding the assessment process. On the other hand, some teachers preferred to use the term distance education, as they not only confine themselves to online meetings but also provide additional resources for children and parents. Furthermore, not being able to physically touch children and sharing the same physical and social-emotional environment have been expressed as additional justifications for adopting the term distance education. One teacher stated that they used both terms to define their new way of providing early childhood education as:

> We generally use both terms; both online education and distance education. With distance education, we refer to the sources we send out to parents such as videos or weekly newsletters, bulletins listing our expectations from parents.

Another teacher stated that she felt more comfortable with the terms online education as it also implies the interactive notion between the teacher and the children. Conversely, one teacher explained:

> I would prefer distance education because we cannot physically get in touch with children. As you would know in early childhood education being within reach physically is vital in order to get their attention or to engage them in the activity. However, we are completely distanced right now.

What we found to be striking is, while constructing the new way of early childhood education, all the teachers were trying to find out their own definitions, paths and concepts about the post-pandemic type of education. Likewise, one teacher stated that they were not prepared, both individually and institution wise: "*I also talked to my colleagues in other institutions and saw that they were proceeding with their already existing system. So I think of it as online lessons and online classrooms.*"

While there wasn't a consensus on the term to define the new way of early childhood education, the same issue was evident for defining the purpose. Teachers determined their own purposes according to their own understanding of the phenomena and their own experiences of the pandemic. However, despite the lack of an informative framework provided by the administrations, teachers constantly stated that they were always in contact with each other through online meetings and discussions for sharing resources and exchanging information. One teacher stated:

> We managed it as a team, by supporting each other and by sustaining each other. Noone, even an academician, or an administrator should lead the team or get to decide without, let's say, serving in the kitchen. You can never grasp what we are experiencing with children in that 30 minutes by only being online for 1 minute or so. You cannot judge or draw a general line about being a teacher in this process. I cannot say that we get enough support during the whole transition process.

Another teacher stated: "*We did not get any training, we were pushed into the new program, and found our own ways through our research, watching informative videos about technological platforms. It was more like, wow! We can share our screen, or wow! We can enable children to draw online.*"

"*It was a totally new phenomenon for all of us. We were all starving for information. The solidarity among us has served as a guide during the most uncertain times*" said another teacher. It appears that almost all the teachers participating in the study tried to keep their heads above the water and found their own paths in a chaotic, unclear and undefined environment. What they depended on were their research, adaptation skills and the solidarity they created spontaneously. Hence, adaptation was another important notion defining the transition to the new way of early childhood education practices for teachers. One of the teachers summarized the process as:

> We got tired of adapting. There was something new happening every day and we were not able to conclude the day as we started. There wasn't much for the school administration to do as well.

Early childhood institutions were the ones, which immediately started online education for children and families one week after the first lockdown. Therefore, almost all the participants reported that they did not have much time to be prepared for or to digest the changes and to design their plans for the near future. One teacher said: "*Every day, we think about what is going to happen the next day. Are we going to go to school next week? What are we going to do in the meantime?*"

Once the teachers set the stage for post-pandemic, i.e. online education, and it became evident that the situation is not that temporary, the institutions began their search for finding the most effective, most satisfying and the best option for children and parents. One teacher described the process as: "*Every week we tried a different system, and it continued like this for approximately one month. For me, it was necessary, but it did not feel good for parents, that I can tell for sure. They were like: we have just got used to this system, is it changing again?*" Likewise, one teacher said:

> At first because nobody knew much about the new system, so many changes were in place. We knew there should be some sort of stability, and we felt like the changes were too much as well. We were trying to create a routine for these people (parents) but also were trying to get there by experiencing as many different versions as we can. The continuous changes asked by the school were difficult for us at the beginning, but now I can say that they were all necessary.

Another explained the situation as: "*By trying all the different versions we reached our current practice.*" It appears that simultaneously, keeping up with the new way of education and dealing with the consequences of the pandemic itself has been a great challenge for the teachers. However, almost all the teachers were satisfied with the outcome. The statement of a teacher was like the summary of that:

> Eventually, everybody was happy with the outcome. The final survey indicated that out of 150 students' parents there were only two complaints, which were related to screen time.

### 2.4.2 Negotiating for the "New Way:" Parents, Administrators and Teachers

The process of searching for a new way in online early childhood education revealed different expectations and perceptions of parents, administrators and teachers. The gap between public and private schools increased due to both financial resources and technological infrastructure. Several teachers from the privileged (and private) institutions, who are integrated into our study, indicated that they took support from the information technologies department, while others might not have such a chance. Another significant difference among institutions was how they presented educational content. Most of the institutions wanted teachers to prepare "asynchronous" lessons, which signified the digital competency levels of teachers. They had to learn how to make videos, edit them, and prepare attention-getter presentations in the meanwhile.

While teachers discovered that they were alone within that process and they had to deal with the problems that occurred in online education, they also understood that an interactive classroom environment was crucial for supplying children's needs. Some of the participants told us that school administrators helped them with the stationery equipment, whereas some told us that they had difficulty in accessing materials, creating a challenge in practice. Those practical problems forced all subjects to achieve a negotiation. In several schools, parents needed to get materials like paper, pens, painting, scissors ready in front of their children during the online meetings themselves; in the others, school administrators provided the equipment for both teachers and children.

One of the issues that arose during the transition to online education was meeting the expectations of parents. It seems that teachers and parents had different understandings regarding the online education process, hence, different understandings caused different expectations.

Teachers defined their purpose in online education as "*helping children pursue the rhythm and follow their routine*", "*staying in touch*", "*spending good time together and having fun*", "*not losing the sense of community they had*", "*making sure that each child expresses himself/herself*" and "*feeling good about themselves and feeling comfortable.*" Almost all the teachers stated that they were determined not to force children to sit still in front of the screen and be engaged all the time.

> When the parents said their children are falling behind in their learning and development and asked how they will catch up with next year's academic goals, I keep saying that academic drawbacks are the last things that we think about. Of course, it is a significant issue, but right now we have other things to focus on.
>
> We remind the parents that we need to keep away from academic concerns.
>
> Some of the parents ask for more online meetings, some say that they have difficulty in persuading their children to join in online. Differing expectations and demands of the parents were a challenge.

As can be seen from the expressions of teachers, academic orientation was one of the negotiation issues. While teachers were more prone to listening to the voices and needs of young children and envisioning a smooth transition, parents and inevitably the administration tended to fill in the gaps for academic requirements. In addition to academic concerns, extended hours of online meetings were also a highly stressed demand of parents both from the administrations and the teachers. Making comparisons between schools and expecting the same practices from their own school appeared as major challenges for teachers. One teacher stated: "*Some parents were so demanding, some even tried to set the hours for online meetings.*" Another teacher said: "*Some parents told us that 15 min every day is not enough, the frequency and the duration of the lesson should be increased.*"

Even though all the teachers stated that academic goals and concerns were not among the teachers' priorities in online education, labels and terms that teachers used to describe their practice were highly academic-oriented and, unlike face-to-face education, mainly teacher-centred. While teachers generally referred to their meetings as online lessons, they referred to the activities they send out to parents as worksheets and homework. Considering that all the schools where the teachers worked, value and emphasize learner-centred education, and teachers' role is confined to guiding children's learning, the emerging emphasis on these terms was also an additional feature of a new form of early childhood education; so it can be considered as an outcome of the negotiation. As the barriers between school and home environment were clear in face-to-face education, the terminology used by each party got to be separate as well. Parents may not be so accustomed to the terminology, and the concept of learning in an early childhood classroom; these terms may still not be within the daily language of the teachers if there weren't this much interaction and transmissivity.

On the other hand, parents had an awareness about the difficulties early childhood teachers had to deal with; for instance, a participant told us that "*most of them supported us, they understood our feelings, they also realized that being a teacher is not as easy as it seems.*" Occupational satisfaction became a striking factor in the shift from traditional education to online practices: That was one of the challenging parts for several teachers. A participant, who was working with 3-year-olds, complained about the common perspective about preschool teachers and about how people used to see them as "babysitters" instead of "teachers." She especially stressed how the parents of younger preschoolers worried about their children's basic physical needs and added that with online education, the effort teachers paid has become visible. She indicated that parents began asking questions about the academic learning, social, emotional, and cognitive skills of the children. In general, the participants expressed that parents eventually start seeing the significance and value of their profession by saying that "I appreciate your work so much," "we understand you," "you make a great effort!".

### *2.4.3 How to Build an Online Classroom as "Apart but Together"*

Following the negotiation process, a new way of early childhood education has been established. Even though the format and ways of education altered, most stated that once it became clear that they would continue online, they proceed with their ongoing curriculum. One teacher said:

> For sure, our existing plans and programs were of great help. I mean, significantly, our team consists of experts in terms of curriculum. We carried on our plans and weekly meetings. The only difference was we were not physically at school, but with all our know-how we tried to run things as before.

Similarly, one teacher said: "*Just the same. I do the same things in the online classroom.*" There were opposing views among teachers on this matter, however. Even though they continued with their already existing curriculum, designed for face-to-face education, some of the teachers also stated the inappropriateness of current online education. As one teacher said about time limitations in the online platforms: "*Online education is not convenient for early childhood teachers, not at all!*" Another teacher complained about the time constraints:

> How will it ever be possible for us to introduce the activity, then to conclude the activity and also to make sure that each child has a say in between, within such a short period.

Since it was too challenging to give an equal say to all children during a limited time, teachers tried to re-arrange the number of students participating in online meetings. For instance, three different online sessions were held to allocate 18-children who were in the same physical classroom. While some teachers preferred to narrow down the number of children in online classes to three-four children at once, some preferred to meet with five or six children at once because they could only see five or six children on the screen simultaneously. Being able to see all children on the same screen is about the design of online meeting platforms, which they used, but based on what we heard from teachers, the highest number for online class size was six.

With online education, the meaning attributed to the shared environment has also changed. Even though they are all physically apart from each other, six children might gather through screens and still find themselves in a shared environment. It appeared that the teachers experienced problems preserving the "sense of classroom" for young children while everyone was separated from each other. The adaptation of this new environment required teachers to reserve a specific place of their personal space (home environment) as a "classroom corner" so that they could get children's attention, establish a shared experience, and even re-establish a sense of community. Despite that, all the participants expressed that an online classroom environment was possible to achieve, but not sustainable for the future. Some of the teachers particularly emphasized its inconvenience for early childhood teachers. One teacher also told us that they would find online education experiences developmentally appropriate and sustainable for young children, if only they were adapted into blended learning strategies, suggesting a hybrid education model. Most teachers touched upon "mental tiredness" as another difficulty they faced because of online education since they were not used to spending their long periods in front of the screen.

Maintaining a classroom environment when children were in separate physical places was a challenge, particularly to sustain a circle time, which is important to get together as a whole group time in the daily schedule of a physical classroom. Yet so was making children stay in front of the screen throughout the session. A few teachers mentioned "screen time limitations" for younger children and how they felt conflicted while asking their students to sit still in front of the screen. To overcome this conflicting situation they found themselves in, most of the teachers explained how they tried to find solutions, such as taking children's attention and making them move at the same time. Transforming screen time children consumed productively and effectively, teachers tried to re-establish the sense of community for children's social development and to incorporate physical movement for children's physical development. As one teacher told, they had yoga and mindfulness lessons with children, and she used yoga poses during online classes. In addition to yoga, exercising and dancing applications, such as *Just Dance*, was also functional for most teachers.

Similarly, maintaining an everyday life routine was also significant for both adults and children within that perspective. The teachers might have difficulty according to the circumstances at home, while young children experienced a lack of physical movement and in-person interaction. For children's social development, face-to-face interaction, sensory learning and sharing the same physical place with others are essential. As a result, the teachers underlined how they tried to preserve "the sense of community," something they had ensured effortlessly during circle times in the physical classroom. Yet, one teacher said "*we try to sustain the circle*" to continue togetherness, another explained it as "*continuity is important... to make them (children) feel we continue with our already existing classroom.*" The classroom used to be the place of collectivity for the children, hence, the continuity of collectivity was the first purpose of the online classroom environment.

> Our purpose in online meetings is not to educate children. Our purpose is to stay in touch with the children, to have fun when we meet online, I mean not to lose contact. Our aim is not to teach children something, like numbers, or let's say, to develop their visual perception because the process is already so difficult for them either. Sitting in front of a screen is very very challenging, so, I tell the parents "do not force your child if she or he does not want to sit still or get engaged in the activities." However, I have children whose parents make them sit in front of the screen. I can see her mother on one side and her father on the other. The child gets up and leaves, but they bring him back. We experience these kinds of situations, and I feel sorry for them.

Teachers used classroom mascots as attention-getters, which was one of the major challenges for teachers during the online education course. While one teacher preferred to use the classroom mascot because "*a familiar object for children was useful to remind the (physical) classroom once they had*," another teacher told us about how she utilised her personal space to establish a new intimacy with children. Her plants and pets at home became new attention-getters for the children. Moreover, the online environment also provided visual items to take children's attention.

> I tried to use visual content as much as I could, I tried to play music, I used to be like that before, but I had been able to use my body language (in the physical classroom).

*Wheel of Names, Educacandy, Chatterpix, Beecastle, Digibook, Edpuzzle* and *Toy Theatre* are several examples of the digital platforms that teachers utilised to grab children's attention. A few participants particularly underlined that they were able to follow the children's development with *Seesaw*; *Boom Learning* and *Jam Board* were also functional applications they discovered during the process. Applications that enable the use of visual materials have become more significant within digital platforms. In English classes, teachers were already used to adapting visuals for language learning, and other teachers also began to do the same for their classes. One of the teachers indicated that "*Most of the online platforms are for school children because there are texts. So few applications exist for preschoolers.*" Yet, most of the teachers talked about how they adapted their lessons such as "*science, art, physical exercise and language*" through "*experiments, activities, yoga-mindfulness, and online applications*" respectively. They had been familiar with *Seesaw*, but they also began using *Movie Maker* and *Sway* for asynchronous lessons; *Zoom*, *Microsoft Teams, Google Meet/Classroom* for their interactive classroom during the online education course. Experiments, in particular, became important sources for teachers to provide student-centred learning and enable active participation during science lessons.

A virtual classroom was constituted within all those experiences; however, establishing an inclusive and interactive classroom environment became more challenging that "what parents and caregivers currently do to support learning with traditional in-school practices can be included in the design of the virtual lessons" (Fox, 2020: 138). As one teacher suggests during the design of the new way of education, "*there should be a virtual classroom contract, of which both teachers and children must agree upon.*" A *convention for the virtual classroom* seems to be a new requirement for the adults (the parents and teachers) and eventually for children. They both need to follow the rules, but also they need to have a say. As we could not interview the children for this study, we tried to listen to how they experienced the current situation from the teachers.

During the interviews, teachers also told us about how children had difficulty adapting to the "new way of early childhood education." Interestingly, children were the only individuals who had no expressed expectations or did not have a right to be involved in the negotiation process, although they were the essential subjects in education. As stated among the priorities of early childhood education, the well-being of young children depends on both the teachers and the caregivers. Hence, we listened out the voices of teachers, not only for their own sake but also for hearing about the actions of other agents in educational settings to comprehend the negotiation for the new learning environment and virtual interaction possibilities for children. As the findings reveal, teachers and parents not only experienced discrepancies, but they also engaged in cooperation to sustain children's needs.

Interaction in the classroom environment and one-to-one relationships among children became significant, so teachers took care of each child individually. Throughout online education, most of the teachers declared that they conducted one-to-one meetings to meet the special needs of each child. We asked the teachers how frequently they met with children as a whole group and what they observed about them during their meetings, both in general and in particular. Even while speaking about the positive sides of online education, a teacher indicated that "*It [online education] is comfortable for me, but I am sure it is not better for the children.*" Thus, we tried to understand how children experienced the new learning environment by inquiring whether they could feel like a part of a community and whether the online platforms had become a virtual classroom or not. A teacher explained the current situation as:

> From our perspective, it was about the continuity of children's rhythm and routines, so they would not lose that rhythm. So that we would not feel the need for an orientation when they come back to school. That was the case for the teachers, but parents wanted their children to do something at home.

At that point, differences among children also matter, as indicated in previous chapters, an inclusive classroom environment is harder to achieve within the online spaces. As one teacher states: "*For children, equal participation is impossible.*" As the teachers expressed, a few children stopped communicating, and for the rest of the children, listening to them was more critical than teaching. One of the teachers underlined that "*educating children was not among our concerns. We just listened to them and their sharings with each other,*" which constituted a specific discrepancy between teachers and parents. On the other hand, online education caused cooperation between different subjects, at which both the age of the children and children's interaction with digital devices might become significant variables. For instance, parents of 3-year-olds needed to support their children to use computers or tablets by showing them how to switch on–off the microphone at online meetings, while 5-year-olds had already experienced face-to-face communication through digital platforms. Technological devices sometimes became a new game for the children to play together and build a virtual community as much as possible, even children could have a conversation after the education process that a few teachers indicated.

### *2.4.4 Teachers' Agency for Building from Scratch*

As we have presented in the prior sections, teachers' agency was at its highest when the lockdown was first initiated, and the private school administrators turned to teachers to proceed with the education their schools were providing. While this great expectation and responsibility of offering a sort of stability and normality to children and their parents, in the middle of a pandemic, brought along many difficulties for teachers, they also provided space to teachers' for practising their agency.

We saw that in the first months of online early childhood education, social-emotional development was the focus of almost all teachers. Accordingly, they planned their online sessions to build a holding environment for social-emotional well-being such as making every child feel comfortable, supporting children's relationships and interaction with each other, helping children to have fun and reconsolidating the sense of community within the classroom.

> …so that she/he would feel comfortable… not to force him/her. I told the parents that she can move away from the screen and come back whenever she wants… totally fine with me
>
> …Tablets are much more portable. Compared to laptops, they are much lighter, and we had children wandering from one room to another… *(laughing)* … We are in class, but one moment he is in his room, the other... in the kitchen…

Teachers needed to manage the whole process without sharing the same place with children. That was the main challenge for teachers in the beginning. However, the fundamental common knowledge deriving from the interviews is that collaboration among teachers has increased. It is interesting since one of the particular insufficiencies of the online environment might be the lack of cooperation during the education process. For example, a few teachers complained about how they felt lonely in the beginning, lost their motivation:

> We were asked to support the children [by school administration], but there was nobody to motivate us.

As a matter of fact, teachers needed to develop "solidarity" among themselves as active agents. Because of the new experience of teachers, they were most eager to share knowledge and some defined the collaboration experience itself as "solidarity." Most of the teachers considered that their dialogue has become more effective.

Considering how the teachers react against the changing circumstances, teachers' interaction with technology, their relationships and potentials for solidarity, and their attempt to improve their skills are essential debates. Teachers also underlined the necessary skills both for a teacher and an early childhood teacher specifically. Despite some participants mentioning how they faced difficulties because of the school administration at the beginning of distance education, the requirement "to be a good teacher" becomes crucial in the end.

> I think there are no good schools, there are only good teachers.

To respond to the question of "what early year teachers do to make this difference and the significance of researching this collaboratively" (Duncan & Conner, 2013: 9), participants signify several requirements, such as teachers need to enhance their abilities, knowledge. To be productive, have curiosity, openness to learning matters for an early school teacher. Most participants found online teaching beneficial to research, cultivate themselves, and figure out new ways for education. The solidarity, information exchange and technological competence of some of the teachers appear to be the major driving forces for teachers to exercise their agency. They arranged the schedule i.e. the frequency, duration of online meetings, group sizes and decided on their choice of materials and learning experiences.

Once the teachers overcame the initial shock and established some sort of a routine with children online, they began to search for new and best options to enrich their online learning experiences.

> The more I pulled myself together and constructed diverse materials, the same thing happened for them. Right now where I stand is so nice, and yes, I can do this for another month. I may not do it happily but efficiently with children.

About the daily and weekly schedule, one teacher says: "*By the way, it was our choice to make. They said those who prefer can divide the class into three or into four. Thanks to god that we think alike with my partner. The lesser number (of children in an online meeting), the better*."

One teacher describes her choice of materials as: "*Frequently using big boards… writing on big boards… placing visuality before anything else*." Another teacher shared her learning environment with us like that while showing the billboard on the wall: "*as you can see, these are my learning environment*!".

Learning experiences that will enable children to be active online, intrigued, and resemble the ones in face-to-face learning environments, were the major factors in teachers' decision-making.

> We made something we called ice jam for example. We introduced the topic with the discussion of how to preserve food when there is no refrigerator. We will make pickles next week. We did this from scratch *(while showing the slides).*

Another teacher said: "*…we are gonna experiment tomorrow. We're gonna mix vinegar with baking soda and blow up a balloon. We gave a list of the needed materials beforehand and told children to bring them along for the class. What else… origami, phonics instruction. I said find something which starts with letters for example. Common, let's get up, and find that in your house!*".

Teachers underlined creativity as a necessary skill for themselves especially during the new way of early childhood education. Due to online education, the teachers had to replace the materials in the classroom with things that would be available for each child in their home environment. As a result, they needed to depend on their creativity more than they ever did before. As indicated above, they sometimes adopted the existing practices to online platforms, sometimes, they developed brand new according to technology-enhanced learning. Some of the teachers gave examples of how they converted the classroom mascot into a virtually shared homework practice. They brainstormed how to adopt their traditional practices in classrooms.

Teachers' agency became stronger while developing new perspectives during that adaptation. Moreover, seven participants said that they had the chance to improve their skills, and had enough time to research their profession to become better at their work. For instance, one attended online meetings about online education, another learned about *Waldorf*. A teacher said she wondered about *Forest School* and had the chance to investigate.

Five participants claimed that the preparation process was more comfortable for online education. While several teachers complained about the mental burden of being in front of the screen for hours, some of them found online education "flexible" and "productive." One said that she was able to control her schedule better: because she did not have to go to work, working from home saved her from time-consuming actions.

> I didn't improve myself so much. I directed myself to various areas, but in the meantime, I had the chance to encounter different tools.

While planning for the online learning experiences, parents' resources at home were among the major considerations of teachers. Especially while recording videos at home for asynchronous teaching, they thought about whether the child can have that material at home or not, how to adapt the activity so that children can perform with the easily available materials.

Always being in search of finding new learning experiences and new materials seem to be a challenge for teachers but were also the opportunities for teachers' decision-making and for practising their agency. One teacher said:

> In the beginning, we were doing things like a show and telling them, but then they seemed to be distracted. While one child was talking, the other was getting bored. Even if there were four children, it took at least two minutes for each child. Then we decided that they should have something to hold in their hands and should be busy with something so that they would not get distracted.

However, as the duration of online education expanded due to the prognosis of the pandemic, the pressure over the teachers from both parents and administrators increased in addition to the difficulties of keeping children in front of the screen and providing attractive, creative and new learning experiences. The extension of online education has become a major problem for parents and administrators as well. Therefore, the demands and concerns of both parents and administrators also became a pruning factor for teachers' agency. All the teachers were employed in private institutions and how parents' demands are handled may be a byproduct of a private sector-customer relationship.

> One of the teachers stated that: "*The support I received was only from my friends. The administration sees the situation as you are a private sector employee, and you receive compensation for your work. In fact, it became kind of threatening, and I began to feel really uncomfortable.*"

Difficulty in finding new sources and new learning activities, the anxiety of parents regarding their children's school readiness and the reservations of the administrations about not being able to meet the demands of the parents led to the increased tendency towards teacher-directed experiences. One teacher expressed this shift in learning experiences as:

> As if something happened here [in online education], we shifted from a child-leading process into teacher-leading somehow.

Technological competency became a significant feature for teachers. The participants discovered their powerful or weak sides about technology usage. The ones, who claimed they were digitally competent, generally indicated their age as the main reason. Regardless of their age, the teachers who get along with technological devices better seem to be proud. A few of them, who have noticed they were not sufficient about digital technology, indicated that they need to develop their skills:

> Educational technology is my weakness, as I see. Although I am younger and I belong to the newer generation, I have many deficiencies.
>
> We learned about it during the training provided by the IT department. As I have a special interest in this area, I immediately try it whenever something new comes up. Actually, it is some sort of enhanced *Powerpoint*, plus you can add the voice component. I wasn't able to do it due to technical difficulties though. (*showing the prepared activity on time concept. There are animations of clocks.*) I gave up using this and bought a physical clock and went over it.

Integrating technology was a tool for enhancing the effectiveness of learning experiences. However, it is also related to the teacher's own interests and talents. Besides, it appears that integrating technology was not a requirement in the new way of early childhood education, instead, left to teachers' confidence, preference and as one teacher expressed, "their consciousness." The teacher explained how they tried to fully integrated technology in the learning experiences they provided for children as:

> We do it, yes. We need to spend extra effort though. For example, … There are applications that you can use online. One of my friends quit his/her job at "………," so he/she is involved in programming himself/herself. We worked together. *GEMS*, for example, for building. I am into mathematics. I designed and organized workshops for *MONE* [Ministry of National

> Education]. We have cubicles, for example. Designing cubicles and asking children to tier them up online. For example, there are throwing dice. It taught me brand new things. I mean learning about all these feels great. I mean, I can plan my classes more efficiently for children. I mean, this has been an issue of consciousness in this process. But it is also joyous, and yes, it is doable.

As it was not within the scope of this study, it is not possible to interpret the relevance between the participants' age and their technological skills. On the other hand, such statements that point out teachers' self-awareness might indicate the value of agency from a different perspective. In addition to their digital literacy levels, their tendencies to improve themselves also differ in individual levels. For teachers, the distinctions derive from their digital literacy levels or interest, competence in technological developments, as they indicated.

Even though child-centered learning and child-initiated learning experiences are presented as vital components of these schools' educational philosophies as described in the previous sections, online education practices strengthen teachers' positioning quite much while weakening children's agency. As a matter of fact, we once again came to realize that if only the teacher gains strength and uses her/his agency completely, the child can become a subject too.

## 2.5 Conclusion: Learning from Online Education Experiences for the Future Pedagogies

The digital age and technological transformation bring new opportunities and challenges for the future of education. While trying to reveal early childhood teachers' experiences during this study, we discovered the potentials that online platforms would present for teachers, children, and other agents in early childhood education and the problems especially young children faced. Changing meanings of a shared learning environment in the field of education showed us different dimensions of technology-enhanced learning. Considering the experiences teachers already had, a new way has once been integrated into early childhood education, and it could hardly transform into the traditional models as before; thus, teachers have brought new ideas to develop existing characteristics for the better. We learned from the participants about how teachers improved their skills and what kind of technological devices and online platforms they have found out and utilised. In addition to creativity, productivity, curiosity and openness to learning, they indicated that technical skills and abilities also matter for an early education teacher so that they can keep up with new generations. Digital literacy and competence in using digital environments sufficiently have become required skills for twenty-first century's children and a significant advantage for teachers.

Continuing a new way meant to deal with the endangered circumstances during the pandemic; however, the online environment experience itself suggests different methods for now. Because meeting through a virtual space from a settled distance would not be sustainable for all agents in education, in particular, for children, a hybrid model should be and has already been discussed. Child-centred methods might also build a brand new way for early childhood learning environments as they used to before. The new way mentioned in this paper revealed opportunities as the participants of our study admit that online teaching was helpful to make research, cultivate themselves, figure out new ways for education, and improve their creativity to enrich learning environments. According to the findings, the initial attempt to build the new way of early childhood education from scratch, with ongoing technological developments and involvement of administrators and parents in the negotiation process, became an obstacle in front of teachers' agency. Nevertheless, teachers took control of their work, while their role and responsibilities increased; and they also discovered that online early childhood education brought along a teacher-directed process rather than child-centred practices. Hence, the study reveals that a new negotiation between teachers and children is necessary to rebuild an inclusive and interactive classroom environment. Online education requires teachers' agency and creativity more than before to involve children in educational practices. Just like a teacher suggested, "an agreement for the virtual classroom" is necessary to sustain a new model of education; a hybrid model can only be constructed by children and teacher subjects together because the subjectivity of children depends on teachers' agency.

Considering the study limitations, we should remind that the consequences indicate the circumstances for the most prestigious institutions in Istanbul, so we could not mention such opportunities for the other schools, especially public institutions, due to economic deficiencies. At first glance, it is apparent that within the absence of face-to-face interaction for children, it is not possible to continue early childhood education through an online environment only. On the other hand, the design and use of new apps and technology that will best fit the needs of young children needed; hence, the conclusion of this study can be a starter for further discussions about the future pedagogies in the frame of the twenty-first century technology-enhanced potentials. Teachers can reconsider the existing constructionist approach to adapt their perceptions of early childhood education. The methodology we used for the study may provide to improve online learning practices by building a well-designed environment for children in both online and physical spaces. The pitfalls and potentials of that experience would provide new strategies for the future of early childhood education in the digital age. Through a continuum of collectivity, collaboration and caring of the children community, more research in which children would be involved in addition to teachers is necessary to conduct further.

## References

Angeli, C. & M. N. Giannakos (2019). Computational thinking education: Issues and challenges. *Computers in Human Behavior*, 106185. https://doi.org/10.1016/j.chb.2019.106185

Başaran, M., & Aksoy, A. B. (2020). Parents' views on the family lives in the Corona-virus (COVID-19) outbreak process. *The Journal of International Social Research, 13*(71), 668–678.

Bjorklund, D. F. (2012). *Children's Thinking: Cognitive Development and Individual Differences* (5th Ed.). CA Wadsworth.
Blum, C., & Parette, H. P. (2015). Universal design for learning and technology in the early childhood classroom. In K. L. Heider & M. R. Jalongo (Eds.), *Young children and families in the information age: applications of technology in early childhood* (pp. 164–182). Springer.
Burnett, C., & Daniels, K. (2016). Technology and literacy in the early years: Framing young children's meaning-making with new technologies. In S. Garvis & N. Lemon (Eds.), *Understanding digital technologies and young children: An international perspective* (pp. 18–27). Routledge.
Duncan, J., & Conner, L. (Eds.). (2013). *Research partnerships in early childhood education teachers and researchers in collaboration*. Palgrave Macmillan.
Edwards, S. (2009). *Early childhood education and care: A sociocultural approach.* Pademelon.
Edwards, S., Skouteris, H., Nolan, A., & Henderson, M. (2016). Young children's internet cognition. In S. Garvis & N. Lemon (Eds.), *Understanding digital technologies and young children: An international perspective* (pp. 38–45). Routledge.
Fox, K. R. (2020). Bidirectional benefits from school to home literacy practices in the early childhood virtual classroom. In R. E. Ferdig, E. Baumgartner, R. Hartshorne, R. Kaplan-Rakowski & C. Mouza (Eds.), *Teaching, technology, and teacher education during the COVID-19 Pandemic: Stories from the Field*. (pp. 133–140). Association for the Advancement of Computing in Education (AACE). Retrieved June 15, 2020 from https://www.learntechlib.org/p/216903/.
Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research.* Aldine Transaction.
Havard, B., East, M., Prayaga, L. & A. Whiteside (in press 2016 Jan release date). Adaptable learning theory framework for technology-enhanced learning. In E. Railean, G. Walker, L. Jackson, & A. Elci (Eds.), *Handbook of applied learning theory and design in modern education* (Chapter 31, pp. 646–668). IGI Global.
Joanna, K., Norgate, S. H., Monaghan, P., & Taylor, G. (2021). Developing evaluation tools for assessing the educational potential of apps for preschool children in the UK. *Journal of Children and Media, 15*(3), 410–430. https://doi.org/10.1080/17482798.2020.1844776
Karahan, S., Yıldırım Parlak, Ş, Demiröz, K., Kaya, M., & Kayhan, N. (2021). Annelerin Koronavirüs (COVID-19) sürecinde özel gereksinimli çocuklarının problem davranışları ile baş etme deneyimleri. *Journal of Qualitative Research in Education, 25*, 79–105.
Layder, D. (1990). *The Realist image in social sciences.* MacMillan.
Layder, D. (2013). *Doing excellent small-scale research.* SAGE.
McLean, K., & Edwards, S. (2016). Beginning the conversations about young children's engagement with technology in contemporary times. In S. Garvis & N. Lemon (Eds.), *Understanding digital technologies and young children: An international perspective* (pp. 155–165). Routledge.
McPake, J., Plowman, L., & Stephen, C. (2013). Preschool children creating and communicating with digital technologies in the home. *British Journal of Educational Technology, 43*(3), 421–431.
Mourlam, D. J., Strouse, G., Kindle, K., Chesnut, S. & L. Newland (2020). We came to see, then we saw: A reflection of one school's experience using seesaw for online and remote learning. In R. E. Ferdig, E. Baumgartner, R. Hartshorne, R. Kaplan-Rakowski, & C. Mouza (Eds.), *Teaching, technology, and teacher education during the COVID-19 pandemic: Stories from the field* (pp. 639–644). Association for the Advancement of Computing in Education (AACE). Retrieved June 15, 2020 from https://www.learntechlib.org/p/216903/
Palloff, R. M., & Pratt, K. (2001). *Lessons from the cyberspace classroom: The realities of online teaching*. Jossey-Bass.
Palincsar, A. A., Brown, A. L., & Campione, J. (1993). First-grade dialogues for knowledge acquisition and use. In E. A. Forman, N. Minick, & C. A. Stone (Eds.), *Contexts for learning* (pp. 43–57). Oxford University.
Papadakis, S. (2020). Robots and Robotics Kits for Early Childhood and First School Age. *International Journal of Interactive Mobile Technologies, 14*, 34–56.
Papadakis, S. (2021). *The impact of coding apps to support young children in computational thinking and computational fluency. A literature review.*

Papadakis, S. & M. Kalogiannakis (2020). A research synthesis of the real value of self-proclaimed mobile educational applications for young children. *Mobile learning Applications in Early Childhood Education*, 1–19.

Papadakis, S., Vaiopoulou, J., Kalogiannakis, M., & Stamovlasis, D. (2020). Developing and exploring an evaluation tool for educational apps (E.T.E.A.) targeting kindergarten children. *Sustainability*, *12*, 4201.

Pasnik, S., & Hupert, N. (2016). *Early STEM learning and the roles of technologies*. Education Development Center Inc.

Plowman, L., & McPake, J. (2013). Seven myths about young children and technology. *Childhood Education, 89*(1), 2733.

Saracho, O. N. (2015). Developmentally-appropriate technology and interactive. In K. L. Heider & M. R. Jalongo (Eds.), *Young children and families in the information age: Applications of technology in early childhood* (pp. 183–206). Springer.

Sardohan Yıldırım, A., & Bozak, B. (2021). The supports provided to families having children with multiple disabilities during the COVID-19 pandemic: A case study. *Journal of Education for Life, 35*(1), 154–172.

Selwyn, N. (2012). Ten suggestions for improving academic research in education and technology. *Learning, Media and Technology, 37*(3), 213–219. https://doi.org/10.1080/17439884.2012.680213

Sığınmacılar ve Göçmenlerle Dayanışma Derneği. SGDD (2021). *COVID-19 Pandemisinin Türkiye'deki Uluslararası Koruma ve Geçici Koruma Altındaki Çocuklar Üzerinde Etkileri Raporu* (Nisan 2021).

Tarlabaşı Toplum Merkezi (2020). *COVID-19 Sürecinde İstanbul'un Farklı Yerleşimlerinde Çocukların Haklarına Erişimi Araştırması: Tarlabaşı Örneği.* http://www.tarlabasi.org/docs/Covid-19_Surecinde_Cocuklarin_Haklarına%20Erisimi_Raporu_Tarlabasi.pdf

Turkle, S., & Papert, S. (1991). Epistemological pluralism and the revaluation of the concrete. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 161–191). Ablex Publishing.

Umaschi Bers, M. (2007). *Blocks to robots: Learning with technology in the early childhood classroom.* New York & London: Teachers College, Columbia University.

Umaschi Bers, M. (2020). *Coding as a playground: Programming and computational thinking in the early childhood classroom.* Routledge. https://doi.org/10.4324/9781003022602

Yıldız, S., & Bektaş, F. (2021). Evaluation of the changes in the way of spending leisure time of children in the COVID-19 epidemic with the views of parents. *Gazi Journal of Physical Education and Sport Sciences, 26*(1), 99–122.

# Chapter 3
# Empowering Early Childhood Teachers to Develop Digital Technology Pedagogies: An Australian Action Research Case Study

**Karen Murcia and Emma Cross**

**Abstract** Children's lives are increasingly impacted by digitization and many are exploring from a young age, how digital technology can be used for learning in enjoyable and relevant ways. Consequently, it is more critical than ever that early years teachers feel confident and capable to engage young children with technologies and support their development of digital capabilities. It is recognised that well-designed professional learning is necessary for the development of early childhood teachers' confidence, technological knowledge and ability to generate appropriate pedagogical practices. This chapter reports an investigation into the impact of action research on the professional development of four early childhood teachers working in a Western Australian Early Years Centre. The project was collaborative in nature and positioned the participants as teacher-researchers. Drawing from the qualitative data, including field observations, critical learning stories, and semi-structured interviews, the experiences and 'voices' of the teacher-researchers are shared in vignettes that synthesise their personal critical learning stories and shared reflections. It emerged from the study that the teachers benefited from, working in professional partnerships with opportunities for sharing knowledge and experiences. Evidence is provided that supports the importance of action research for early years teachers' professional learning and their development of quality digital pedagogies.

**Keywords** Digital technology pedagogies · Action research · Professional development

## 3.1 Introduction

Digital technologies are becoming more prominent in children's lives, where most of parents own digital technologies in their home, yet early childhood teachers are reported to need professional learning to build confidence in order to effectively

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design and implement experiences that facilitate children's development of digital capabilities (Donohue, 2014; Mikelić Peradović et al., 2016; Murcia et al., 2018; Zabatiero et al., 2018). It is argued that digital technologies are an integral component of young children's learning and development, as one third of children are using digital technologies daily; children aged birth to two years are spending an average of 14 h per week using digital technology, while children aged three to five years spend an average of 26 h per week (Mantilla & Edwards, 2019). The place of technologies in young children's education is recognised by a multitude of national reports that outline how early childhood educators use technology in the learning environment and the skills, understandings, capabilities, and digital technology fluency and literacy required to teach and learn in the 21st-century, globally (Donohue, 2014). In Australia, the Early Years Learning Framework (EYLF), describes how teachers can guide children's engagement with digital technologies to "access information, investigate ideas and represent their thinking" (Department of Education, Employment and Workplace Relations [DEEWR], 2009, p. 3). With increasing access and an expectation for the integration of digital technology in early years education, it is now more critical than ever that early childhood teachers feel confident and capable to effectively embed digital technologies into learning environments with quality pedagogical practices.

Understanding the requirements for quality integration of digital technologies into early years learning environments, formed the basis of the research project reported in this chapter. The aim of the project was to investigate the impact of action research practices on the professional development of early childhood teachers; facilitating their exploration of digital pedagogical knowledge and practices. The project was initiated in the participating early childhood centre, forming a critical partnership that underpinned research engagement and the service's achievement of a high-quality rating.

Since the Nationalisation of the Australian Early Childhood sector, all providers are required to undertake regular assessment against the seven National Quality Standards conducted by the Education and Care Regulatory Unit. Through the assessment and rating process, all services are awarded a rating of quality ranging from Excellent to Significnat Improvement required (ACECQA, 2020; Neylon, 2015). All Australian Early Childhood services strive to be awarded the highest quality rating: excellent, which emphasises the importance of centres engaging in continual informed improvement of centre operations, influenced by understanding of relevant research, and sustained exceptional practice (ACECQA, n.d.-b). It is essential that Australian early childhood providers engage in research projects to achieve the highest quality rating.

Tangible coding devices or 'robots' were the focus of this research as they are reported to expose children to the fundamentals of computer science, such as design algorithms, structures, and operations through hands-on play that makes learning coding more accessible (Murcia et al., 2020; Stamatios, 2020). Children learn by doing and the tangible nature of the coding interface on robotic devices supports concrete ways of thinking and representing ideas (Murcia & Tang, 2019). Children's engagement with tangible coding devices requires the development of complex problem solving skills, where higher-order cognitive functions are developed, including computational thinking (Stamatios, 2020). Playful learning experiences with digital toys can create demands for children's computational thinking and, with an open and integrated teaching approach, may provoke inquiry learning experiences.

Drawing from the qualitative data, including field observations, critical learning stories and semi-structured interviews, evidence is provided that illustrates the impact of action research on four teachers' development of foundation digital technology capabilities. The following chapter begins by conceptualising action research in professional development, illustrated by the experiences and 'voices' of the teachers are shared in vignettes that synthesise their personal critical learning stories and shared reflections, and supported by identification of the emerging themes observed in the teachers' growing digital capabilities and pedagogies are then compared and discussed. In this chapter, the opportunities observed for integrating digital technologies into the early years environment are documented and evidence is provided that supports the importance of action research for teachers' professional learning and development of digital pedagogies.

## 3.2 Integration of Digital Technologies into Early years Education

Despite the Early Years Learning Framework's requirement for integration of digital technologies into early learning services, research suggests that many early childhood teachers utilise digital technologies as a substitute for traditional tools, as opposed to an extension of curriculum (Blackwell et al., 2014; Thorpe et al., 2015). Hesitations to integrate digital technologies into learning environments have been identified, stemming from inadequate professional development opportunities, teacher misconceptions, and a perceived lack of value for learning (Blackwell et al., 2014). As digital natives, most children are able to adapt to digital technologies quickly, but require support to navigate situations they do not know how to manage, thus emphasising the importance of quality support (Chaudron et al., 2015). When teachers are confident and competent at integrating digital technology into the learning environment, they are better equipped to develop programs that focus on enhancing children's learning and development of digital literacies through quality learning experiences (Mantilla & Edwards, 2019; National Association for the Education of Young Children [NAEYC] & Fred Rogers Center for Early Learning and Children's Media, 2012). Therefore, teachers require meaningful and relevant professional development opportunities to build the confidence and competence necessary for quality digital technology integration into early year's services.

## 3.3 Action Research for Early years Teachers' Professional Development

Action research has been reported to be a powerful tool for supporting teacher's professional development as it connects with their lived experiences and has direct relevance to their practice. Action research can be understood as a teaching process providing development for those involved, where the emphasis falls on enhancing practices rather than solely producing knowledge (Elliot, 2001; Carr & Kemmis, 1986). By enhancing practice and creative potentials, teachers are empowered to create new realities and construct professional knowledge (Bognar & Zovko, 2008). Action research is an interpretivist research approach, whereby researchers act on the assumption that reality is dynamic and constantly changing through social processes (Checkland & Holwell, 1998). Through this perspective, there are four critical elements that underpin an action research approach: collaboration between people involved in the situation, critical inquiry, emphasis on social practices, and deliberate reflective processes, where themes replace a traditional research hypothesis (Checkland & Holwell, 1998).

Well-designed professional learning is necessary for the development of early childhood teachers' technological knowledge and ability to generate appropriate pedagogical practices. Moreover, teachers benefit from working in professional partnerships, that provide opportunities for sharing knowledge and experiences (Murcia et al., 2018). It is argued that action research is a vital process for the development of early childhood teacher's digital technology skills and practices.

There are four general stages of an action research project. These stages are, identifying a research problem, creating a solution, implementing the solution, and reflecting on the effects of the strategies (Borgia & Schuler, ). The following brief overview summarises the steps outlined by Efron and Ravid (2013), where teachers select and research a topic, determine approaches and a plan for the research, collect data, and assess the data collected. Gummesson (2000), highlighted the dynamic nature of action research, and suggested that the following four stages may not always be linear in nature, rather regularly occurring concurrently.

1. *Identify research problem*

The first step in an action research project is identifying the research problem or focus. It is during this time that teacher-researchers will reflect on their own work and practices; deciding focal areas that are relevant and meaningful to their own personal and professional growth (Efron & Ravid, ). Teacher-researchers may search for general information, resources and prior research literature in the area to make an informed decision regarding the direction of their chosen research topic.

2. *Create solution*

Creating and designing a potential solution to the identified challenge is the task of the teacher-researcher. In this step, the practitioners develop research questions that will guide the purpose of their study and provide insight into the research problem

(Efron & Ravid, ). After determining the guiding questions, teacher-researchers will consider a range of possible approaches and determine which research method will be the most appropriate for the project and, for developing a plan of action (Borgia & Schuler, 1996a, 1996b; Efron & Ravid, 2013a, 2013b).

3. *Implement solution*

Implementing the plan and potential solution is the third step in an action research project (Borgia & Schuler, 1996a, 1996b). During the implementation stage, teacher-researchers maintain detailed records of data (Efron & Ravid, 2013a, 2013b). Teacher-researchers may use a number of different qualitative, quantitative, and mixed data collection methods, including observation, interview, survey, and artifacts and documents (Efron & Ravid, 2013a, 2013b). Implementing the solution has been described in literature as another element that develops the researcher's understanding of the research question, enhancing solutions, and potentially raising additional questions (Kemmis, 1988).

4. *Evaluate and reflect on the effects of strategies and plan follow up activities*

After implementing a solution, teacher-researchers may have gained an extensive amount of raw data (Efron & Ravid, 2013a, 2013b). It is at this point that the researchers will analyse the data and begin to make assumptions and draw conclusions. Through this analysis process, teacher-researchers evaluate the project and reflect on the effectiveness of the strategies employed. With this greater understanding, teacher-researchers are able to plan follow up activities to support the project or begin planning concurrent research projects (Efron & Ravid, 2013a, 2013b; Murcia, 2005).

Across all stages, working with a critical friend is an important component of the action research and professional development process. Critical friends can be understood as colleagues that are engaged in the same process of learning, supporting ongoing sharing and reflection by colleagues who share a common interest and understanding in the project's process and goals (Murcia, 2005). Engaging in professional conversations regarding an action research project allows the teachers to clarify their thinking and share a variety of perspectives and interpretations. Working in collegial groups, teachers can share the workload and enrich their outlook on the project. Being a critical friend requires a trusting relationship, where teachers can freely express themselves and share their experiences and struggles (Murcia, 2005). By maintaining a critical partnership, teachers are exposed to different perspectives and experiences, which challenge and enrich thinking and reflection.

## 3.4 A Cycle of Planning: Implementing Digital Technology Practices

The Australian early years sector is governed by the National Quality Framework (NQF) and Standards, which provide clear indicators for quality practice and pedagogy (Australian Children's Education & Care Quality Authority [ACECQA] (2020). The NQF can be used to support teachers' reflection, planning and implementation of digital technology learning experiences with young children. For example, Quality Area 1 relates to the "educational program and practice" with three elements that compose Quality Area 1; program, practice, and assessment and planning (ACECQA, 2020). The planning cycle outlined by ACECQA (2020) is built upon five phases: planning, implementing, reflecting, observing, and analysing. These steps align with an action research approach, where teachers identify potential problems through their observation and analysis, create a solution during their planning phase, implement the solution as they implement their planned learning experiences, and reflect on the learning experiences and the effects of the strategies they implemented through their action research project, planning follow up activities accordingly. We propose that there is a synergy between quality planning, action research and the professional development of early years teachers. Many teachers in the Australian early years sector are already employing these principles in their daily practice and development of curriculum (Fig. 3.1).

## 3.5 Methodology

Social constructivist principles underpinned the research design and the positioning of the participating teachers as practitioner-researchers (Glassman, 1996). This approach enabled the achievement of the action research project's two main objectives; firstly to develop and engage young children with inquiry investigations that meaningfully integrated tangible coding technologies and secondly, to enhance and improve teachers professional knowledge and digital technology capabilities. The teachers collaborated as researchers, making observations, collecting data and contributing to analysis which, provoked their own meanin-making and construction of knowledge, through both individual development and social interactions. It is argued that the modern constructivist approach is in many ways formalising a process that many teachers had already introduced and aligns with the planning cycle (Rout & Behera, 2014).

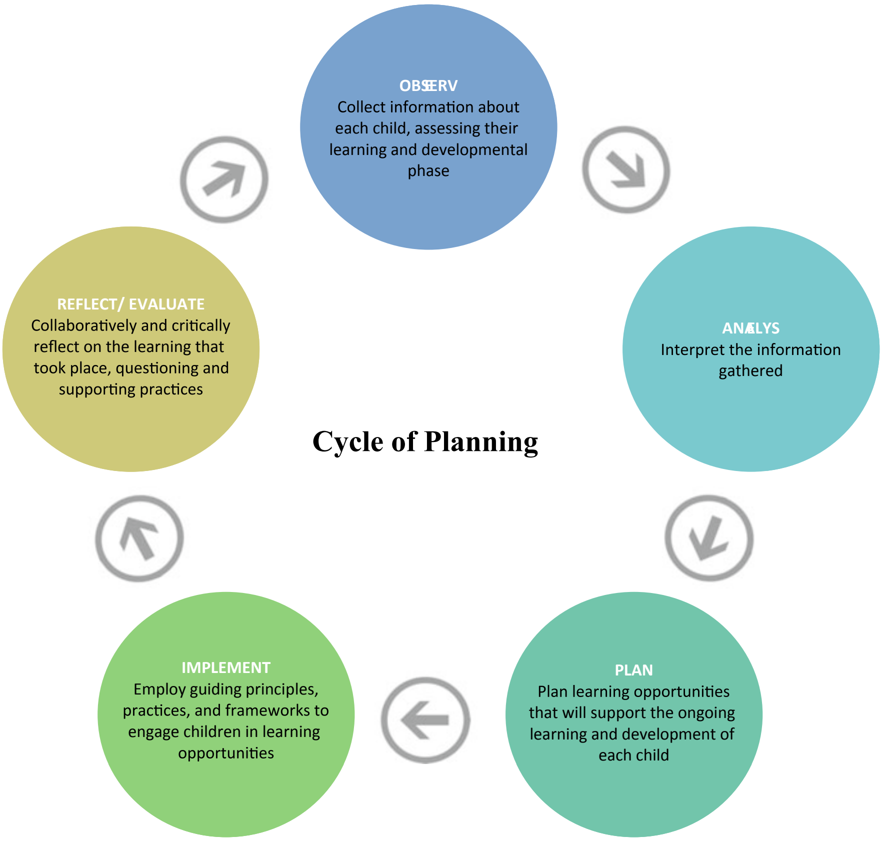


**Fig. 3.1** Cycle of planning

## 3.6 The Study: Exploring Digital Technology Integration in an Australian Early years Centre

This six-month project involved teachers from an Australian metropolitan university's early years service. The service was used by students and staff of the university, providing long day care and education to children aged eight weeks to four years of age. However, the four teachers participating in this study were working into the kindergarten program, where children are aged three to four years. The teachers invited two focus groups of children to join the research project based on their parent's signed consent and general interest and engagement with digital technologies. Each focus group included a maximum of 5 children. However, the number participating in each activity varied as in this learning environment, children's agency was valued and they could choose to move between experiences.

The research project included professional learning workshops, and formal briefing and debriefing meetings with the teachers. Over the period of the project, there were three cycles of action research. Each cycle was 4 weeks in duration and included planning, implementation and reflection on children's experiences with digital technologies. Initially, two types of digital coding toys were introduced to the children. Firstly, Cubetto which is a 'friendly' wooden box that is open to a child's imagination and the creation of a character (https://www.primotoys.com/cubetto/). This product includes a coding board with shaped pieces used by children to create coding patterns that set Cubetto exploring the environment. It was created by Primo Toys (UK) with a range of floor maps that represent different worlds, from under the sea to outer space. Cubetto is an innovative digital coding device yet it incorporates traditional play patterns of colour recognition and shape sorting. It is a tangible coding tool with a physical programming interface that facilitates young children's engagement with foundation coding principles; sequencing, debugging, and functions. Secondly, Bee Bots were also introduced through the project (https://www.teaching.com.au/catalogue/mta/mta-ict-robotics-bee-bot). These colourful toys have a mechanical interface, which requires children to count movement units and recognise symbols for direction as they press buttons that code or 'instruct' the bee to explore their world. In a third cycle of action, iPads were introduced to enable children to explore a digital interface for coding. This screen-based activity incorporated coding capabilities, which were anticipated outcomes of children's prior experiences with both Cubetto and Bee Bots. The iPads were locked to the Apple Bee Bot app to maintain children's focus on the coding and to prevent them from accessing unplanned materials (https://apps.apple.com/au/app/bee-bot/id500131639).

An inquiry approach to children's learning was valued in the centre and demonstrated by the teacher-researchers. Children's interests and agency drove planning and the activities facilitated in each action cycle. Typically, experiences with the intentional introduction of a provocation and guiding of the children's play with a digital device were planned for 30 min. However, the amount of time the focus children spent engaged with an experience varied and the length of each learning project was dependent on their interest and engagement. The teacher-researchers aimed to design and guide learning experiences that were developmentally appropriate and meeting the interests and learning needs of the children. Reflecting on the children's technology capabilities through the lens of the EYLF, provided powerful professional learning for the teacher-researchers and informed their planning and practice. Table 3.1 shows how the digital devices were introduced into each Kindy Room across the three cycles of action research.

The qualitative data collected during the study and presented in this chapter included both semi-structured interviews and a professional learning story written by each teacher that captured their reflection of a critical incident in their professional learning. Critical incident reflection is a way to produce narratives based on a participant recall of an experience (Maternal & Child Health Nurse, 2007). A framework was provided to the teachers to guide their reflection and writing. This framework assisted teachers to identify key professional learning moments and develop depth in their reflection. There were three elements to the framework:

**Table 3.1** Introducing digital devices into the Kindy Rooms

| Action research | Kindy Room 1 | Kindy Room 2 |
|---|---|---|
| Cycle one | Integrating Bee Bots into literacy and science inquiry projects | Introducing Cubetto through exploratory play |
| Cycle two | Planning and constructing grid play mats for Cubetto and children reading and symbolically representing code | Programming the Bee Bots to navigate the Kindy Room and using direction cards (symbols) to work out a coding sequence |
| Cycle three | Small group experiences with the iPad Bee Bod coding App and exploring strategies to build children's directional language and understanding of orientation | Guided introduction to the iPad and individual children's play with the Bee Bot Coding App |

1. *What?* A description of the incident, which includes factual information, observations, and details of the context.
2. *So what?* The sense-making component, where the teacher draws general meaning and significance from their description of the event.
3. *Now what?* Making connections from the experience to further actions based on interpretation of the event and the learnings gained.

Narratives are a commonly used qualitative research tool with multiple definitions (Polkinghorne, 1995). The focus of this study was on narratives as a story to share experience, understanding and new insights. As the teachers moved through the action research cycles, they engaged in a variety of experiences and opportunities that contributed to their professional learning journey. The teachers' experiences built on each other and couldn't be delt with independently of one another. Rather, these events were framed as larger structures and were reflected as such (Polkinghorne, 1995). By employing narratives as a story to explore the impact of our project, the teachers' voices were encapsulated and reflected in our findings. The following teacher stories are a synthesis of their critical incident reflective writing, discussions and comments drawn from the semi-structured interview.

### *3.6.1 Emily's Story*

I started by introducing the children in my room to Cubetto. I chose to have small group sessions initially, so I could talk with the children about respecting and taking care of the technology. I used expressive storytelling to create excitement about a new 'friend' joining the group. Together we discussed and negotiated boundaries and guidelines before Cubetto could come out to play. This included not picking up or touching Cubetto while on his map, but rather only touching his board and chips. The children were fascinated with the idea of communication and how we could talk to Cubetto. The electronic 'twinkle' sound made when turning on the device became

Cubetto's way of saying hello. The children were keen to understand how we could talk to Cubetto and how he could 'hear' or 'understand' when they asked him to go forward or turn.

During the experience, I aimed to ask questions that directed or guided the children's activity and thinking rather than telling them exactly what to do. I wanted them to experiment with placing the coloured coding chips on the coding board and seeing what effect each had on how Cubetto moved. They were talking together and collaborating. Turn-taking had to be reinforced as some children were very keen to try out their own ideas. I noticed children offering suggestions and alternate ideas to the child who was having their turn. It was exciting to see how quickly they discovered that the coloured chips were a symbol representing movement and direction. The challenge then became creating a sequence of instructions, by placing coloured chips on the coding board, so Cubetto would travel to the desired destination on the grid play mat.

The compass points on the Cubetto play mats were another representation of direction that became integrated into the children's experience. Over time they increasingly used directional language such as left, right, turn, forward, up, and north. These terms and concepts became part of the children's shared language and they were often seen layering their communication with gestures, such as pointing, waving, and even whole body turns to check direction.

This is just one example of the learning design experiences we engaged the children with during the digital technologies project. I have reflected and realised that before the project, I didn't really understand the value of technology in the early years. I thought that the children were too young to meaningfully use digital technologies and that it would stop them from learning and engaging. I hadn't taken the time to learn about the different types of technologies or even really considered what the difference was between software or coding and the interface types on the various devices. I didn't know what types of technology were available and appropriate for early childhood education. This project certainly made me reconsider my understandings. Now we've got an iPad in the room and the children do things on it for short periods of time. They are even taking photos using the camera and setting the timer to monitor a whole range of activities. All those little things are now integrated into the learning environment. This project has made me think more about how to integrate technology into learning environments, children's development of digital skills and how I can use digital technologies to be a better teacher.

### *3.6.2 Lauren's Story*

The Bee Bot was the first coding robot that I introduced to my children. They automatically made a connection between their favourite story, 'Willbee the Bumble Bee', and the Bee Bot robot. This was really exciting and created an opportunity for a great science inquiry activity; learning about environments and the living needs of a bee. Exploring environments become an inquiry theme that drove the children's learning with the digital robot they now befriended and named Willbee. We continued our integrated curriculum approach rather than using the technology as a separate experience or thinking about it as simply ‘technology just for technology’s sake’.

The children were interested in the range of places Willbee could visit in their centre and this provoked a range of questions about what a Bee needed to survive The children created their own play mat environment that had features from their centre and its garden. The places on the mat became a world for Willbee to explore and the children told stories about his adventures. While watching the children play we became curious and questioned if the children could recognise and read coding symbols that represented the range of journeys they had planned for Willbee. Amazingly, not only could they read and perform the symbolic code shown to them but some were also writing their own coded stories.

The project made me think more about the way I teach. I’m talking a lot more to the children about what they’re doing. I role model more and ask questions like “what happens if we do this?” I’m using a range of open questions, and explorer questions such as, “how can we get Willbee to the other side of the room?” How can we get Willbee up the ramp? My practice has changed, as I’m more likely to go with the children’s lead. But also guide them in a way that they’re learning key ideas and those foundation digital skills. I’m more intentional in what I do with the digital technologies and how I engage the children. I’ve become much more aware of how capable these young children are when they were given the opportunity to explore with digital technologies. These children learned to code with time and practice. Their learning was really impressive and even a little surprising for me.

### *3.6.3 Cait’s Story*

I thought that it would be easy for the children to grasp and master the concept of the Bee Bot coding game on the iPad as they had already used the actual tangible coding devices, Bee Bot and Cubetto. When introducing the iPad Bee Bot coding app, the children actually found it more difficult than we had expected. Orientation was a major issue for the children as the directional arrows for coding in the game were fixed, rather than moving in the same direction as the Bee Bot. When the children were using the app, I had to role model and focus on the use of directional language like “forward, backward, right, and left”. It surprised me that they had such difficulty with their directionality as we had already used these skills with the Cubetto and Bee Bot robots.

My challenge was how to best help the children learn directional language and support them to master the game and complete the various levels. I tried a range of strategies such as turning the iPad, questioning the children, “which hand does the Bee Bot need to turn to?” and turning the iPad back the right way. This strategy worked but was difficult when working with more than one child. After reflecting on this, I provided the children with the actual Bee Bot so they could turn it and face the same way as the Bee Bot in the app and hence be better able to recognise the required directions. This helped, but interestingly, a lot of the children wanted to play with the actual Bee Bot rather than interact with the app. I then decided to make some scaffolding cards with an image of a Bee Bot on them with directional arrows. This was great for the children and they became more independent in choosing which direction the Bee Bot needed to turn as it navigated the game pathways.

While this strategy worked, I wondered if the children really understood which way was right and left. I took a small focus group to the mat and I put a red sticker on the children's right hand and a yellow sticker on their left hand and said to them, "Red, right, yellow left." I chose these colours as these are the colours of the right and left chips that are used on Cubetto's coding board. We then stood in a line and I asked the children to listen to my instructions and follow like they were the Bee Bots in the app. I used the directional language forward, backward, right and left. The children found the stickers a helpful reminder when I would ask them to turn left or right. We then went back to the iPads and used the stickers on hands as a strategy to help with playing the game. The children responded well with the scaffolding and were able to tell me which way their Bee Bot was turning. The children were able to complete the Bee Bot coding game levels, with a colour and hand prompt for left and right, combined with using the directional cards.

Since participating in this project, I've been scaffolding a lot more with the children and trying out different strategies. If one thing doesn't work, then we try something different to help the children learn. Working on the project as highlighted how much early mathematical thinking is involved when coding the robots. I've also realised just how visual young children are as learners, which emphasised for me the importance of concrete scaffolding tools. I found working with tangible coding devices so beneficial for the children in my kindy program and I'm so proud of everything we've achieved.

### *3.6.4 Lisa's Story*

We started with Cubetto, which the children absolutely loved! A highlight for me was when we used wooden blocks from our construction area to build bridges, tunnels, and roads for Cubetto to move through. It was interesting taking Cubetto off the grid play mat because the children were able to explore how Cubetto could move in different ways and on different surfaces. The children were constructing pathways, ramps, and obstacle courses. It was inspiring to watch them troubleshoot the design of their pathways and work out how far Cubetto would go with a single coded action. They had to figure out another way to measure the distance and number of moves required when there were no grids like on the play mats. I think their learning was a lot more valuable because they were problem-solving and working things out for themselves.

After spending time with Cubetto and learning how to code using the coloured chips and coding board, we introduced the children to coding with a Bee Bot robot. We thought that starting with Cubetto would help the children understand the coding process with physical chips before moving to the Bee Bots which, have a mechanical push button coding system. Pushing buttons to ‘enter’ information, didn’t provide the children with a representation of their code in a concrete or observable sequence. Hence, moving the children’s play to the Bee Bots proved more difficult than we had expected. The children couldn’t remember how many times had pushed the button and they frequently forgot to clear previously entered coding before starting again. To help overcome this challenge we provided the children with direction cards which they used to work out their sequence of instructions before entering it into the Bee Bot.

Introducing the iPad Bee Bot app to the children also created some surprising issues. The children knew the basics of how an iPad worked and had previously demonstrated an understanding of coding but they didn’t transfer what they had learnt to the iPad app. Orientation and the directional part on the screen was really confusing for them. The children’s difficulties with their orientation and direction prompted me to collaborate with Cait as she had already trialled the app with her children. She provided me with some really helpful ideas and my children used her directional cards which, helped them to complete some game levels.

In one of our project debriefing meetings, we all shared how our children had engaged with the various coding devices. We were all wondering which was the children’s preferred coding device so we set up a controlled ‘test’. All the digital toys and iPads were set up in the Kindy rooms and then without any teacher direction, the children could take the device they wanted to play with. The majority of the children went to play with Cubetto, some took the BeeBots and no children went to the iPads. While talking to the children about their choice, it was apparent that controlling movement was a common theme underpinning their choices. For example, my children told me “I like them all, they all move”, the Bee Bot moves and the arrows are there” and another child said, “I like Cubetto when he walks.”

Reflecting back on my project experience, I’m now more aware of how children learn; what I’m teaching them and what I’m saying. I use a lot more questions, encouraging the children to think for themselves or to problem solve rather than waiting for me to tell them what to do or how to do it. It’s been rewarding to see how the children are using their technology skills and how they can teach me as well. I have learnt so much through this project and from the children. Going into this, I didn’t know the difference between hardware and software and now the children are teaching me new ways to learn maths skills like sequencing and counting using digital technologies.

## 3.7 Emerging Themes from the teacher’s Shared Experience

Comparing the teachers’ experiences and the information they provided in their reflections and interviews, revealed common themes in their professional learning about digital technologies and how children learn. The action research approach was found to align with the teachers' planning cycles and encouraged collegial interactions and sharing of ideas and resources.

### *3.7.1 Learning About My Own Professional Learning*

Firstly, a key theme emerging from this action research project was the undeniable growth each teacher made with their digital pedagogies. The process provided the teachers with an opportunity to enhance their practices and acquire new skills and knowledge (Elliot, 2001; Carr & Kemmis, 1986). This was evident in Lisa's story as she began the project unclear about the difference between software and hardware. Now, not only does Lisa know the difference, she also recognises the impact digital technologies can have on how young children develop mathematic reasoning and computational thinking. Cait also valued the project and through meta-reflection recognised how she gained professional knowledge. She shared "I learnt the most by being able to go through the experience with the children and being hands-on as well. I think you need to make mistakes and learn from them."

The action research project engaged the teachers and encouraged them to think more critically about their teaching and to develop appropriate pedagogical practices (Murcia et al., 2018). This was evident through Emily's story as she shared her own learning process, realising that digital technologies could be appropriately integrated into the learning environment and used to promote better pedagogical outcomes. Upon reflection with the researcher, Emily elaborated saying, "I was probably a bit closed-minded at the beginning with ideas like inquiry questioning and children coding, but I am a lot more open-minded now. Being in the project, made me realise the importance of research and recognise how it has impacted my own teaching."

Importantly, the teachers were able to develop technological and pedagogical knowledge through the project as they were exposed to a range of new concepts, learning theories and critically reflective professional discussions which, prompted further curiosity (Murcia et al., 2018). Lauren said "it helped to have the theory behind what we were doing, like the transversal capabilities, digital literacy and computational thinking; even just to understand what coding is. But when you came in (researcher) it was awesome and really really beneficial to reflect on what we were doing." The data collected through this research experience highlighted that the teachers were able to learn about their own professional development needs while being guided to build their pedagogical capabilities and enhance their technological knowledge.

### 3.7.2 Understanding children's Engagement with Digital Technologies

Analysis of the collected data provided evidence of all four teachers developing a greater understanding of how children learn with digital technologies in an early childhood service. This was a positive outcome as early childhood teachers have previously been reported to displayed misunderstandings regarding the appropriate integration of digital technologies into curriculum and learning environments (Zabatiero et al., 2018). Emily highlighted her professional development by sharing her initial apprehensions and belief that digital technologies prevent children from engaging and learning. Emily described how her changed practice as a result of participating in the action research project had created learning opportunities for the children. She said, "the children just soak up so much, like when they learned how the interface board and coding blocks communicated with the robot and caused the movements. We didn't even tell them that. They just put things together and knew it was causing an effect." By developing confidence and digital pedagogies, the teachers were able to meaningfully integrate technologies into the children's curriculum.

The teachers made an important shift as they moved to focus on how the children learned and their digital literacy development (Mantilla & Edwards, 2019; NAEYC & Fred Rogers Center for Early Learning and Children's Media, 2012). Throughout the project, the teachers went on their own journeys of exploration and understanding children's learning. Cait shared the different components to the children's learning that she was able to identify, question, and scaffold. Cait realised the importance of careful observation for informing intentional planning and scaffolding children's learning. She shared "it helps to let them have a go first and to explore with the technology. If we found that they were struggling a bit, we would develop a plan for helping them next time." Additionally, Emily realised that "the exploration questions were really moving the children in an intentional way to lead them to find out information and come to a conclusion themselves. They are exploring to find answers independently without us telling them." Lauren shared a similar realisation in her learning story mentioning how she recognised the children's capabilities of learning complex and abstract thinking through repetition and practice. When reflecting on her experience, Lauren shared "I think the children working together in a group helped them learn and share understanding about direction, coding sequences, and even units of measurement. Taking the time to reflect with the children about what they had done gave them a real sense of pride to see what they had achieved." It was evident throughout the analysis of the project data that the teachers increasingly valued playful experiences with digital devices integrated into the children's learning environment. The digital devices became a tool supporting learning across multiple areas but also the children developed important foundations to digital literacy.

### 3.7.3 Critical Reflection and the Planning Cycle

Another important theme that emerged from the data was the role that critical reflection plays in the planning cycle. By critically reflecting, the teachers were able to evaluate their pedagogy and the effectiveness of their teaching (Efron & Ravid, 2013a, 2013b). The extent to which reflection impacted the teacher's planning and pedagogical strategies was highlighted through Cait's learning story. Her ability to purposefully observe the children's learning, analyse observations to determine trends and needs and then adjust her pedagogy to produce better learning outcomes highlighted the impact that critical reflection can have on practice. Reflecting on her learning, Cait stated "I think it's very important to critically reflect because when you carry out the digital activities with the children you then need to go back and reflect upon what happened, how the children went with it, what they learned, and how you went about your own teaching. This is the basis for what you do next time and what you can change to help the children extend their learning." With this greater understanding of the teaching and learning outcomes through reflection, the participating teachers were able to plan meaningful and engaging follow up activities that supported the children's achievement of key learning outcomes (Efron & Ravid, 2013a, 2013b). It was clear that the teachers gained a sense of excitement through the reflection process as they began planning follow-up activities. Emily excitedly shared "as soon as we had finished an activity, we would be mind blown; 'wow this is amazing we can do this and we can try that and it's all because of one activity with Cubetto.' The children just loved it, they got excited about it, so we got excited too." Critical reflection played an important role in the planning cycle as the teachers were considering their teaching and the children's learning. They purposefully reflected and considered how best to scaffold and extend the learning opportunities, so as to enhance the children's digital capabilities and achievement of cross-curricular learning outcomes.

### 3.7.4 Intentionality and Planning to Integrate Digital Technologies

Research has suggested that teachers who are confident with their digital technology capabilities are more willing to integrate digital devices into a learning environment, and are arguably able to plan intentional and meaningful learning experiences that support young children's digital literacy development (DEEWR, 2009; Mantilla & Edwards, 2019; NAEYC & Fred Rogers Center for Early Learning and Children's Media, 2012). Participating in the action research project, the teachers were able to develop their experience and confidence with digital technologies, which facilitated their creativity in the integration of digital technologies into their planned learning experiences (Elliot, 2001; Carr & Kemmis, 1986; Murcia et al., 2020). This creativity was demonstrated as the teachers were able to integrate a variety of concepts and previous learning interests to facilitate the learning and engagement with the coding devices. Cait was creative in her introduction of the Bee Bot into the learning environment, as illustrated by her comment, “the children were interested in Wilbee the Bumble Bee’s song, so we incorporated that into our intentional teaching of the Bee Bots, which showed how the children can grasp concepts through intentional teaching and merging their interests.” Through the teacher’s pedagogical approaches, it was evident that they were using an action research cycle of planning to observe, analyse, plan, implement, and reflect to ensure they were generating meaningful and intentional learning experiences for the children (ACECQA, 2020; Efron & Ravid, 2013a, 2013b). Cait explained her cycle of planning when saying, “we use non-contact time to plan out what we are going to do, then observe the children in their play and use intentional teaching strategies to see what they liked, their interests, and how we can move onto the next activities in their learning journey. The curriculum emerges from the children’s interests and you’re intentional in terms of the resources that you put in the room and the types of questions that you might pose.” Developing an understanding of the children’s interests facilitated a variety of further planning, supporting the integration of digital technologies into the learning framework, where children could investigate their ideas and represent their thinking (DEEWR, 2009). Emily reflected “the children’s love of Cubetto came through in the way we were setting up and planning around it. It probably made planning for the room a lot easier as we planned around Cubetto with a whole range of inquiry activities.” It was evident that the digital devices had been intentionally integrated into the children’s inquiry experiences, through a carefully planned cycle of teaching activity.

### *3.7.5 Sharing Experiences with a Critical Friend.*

Working with a critical friend was an important element of the action research and professional development process used in this project. Developing trusting relationships with colleagues, supported their engagement in professional conversations and sharing of experiences and difficulties (Efron & Ravid, 2013a, 2013b; Murcia, 2005). This was highlighted by Cait when she stated, “working with the other teachers as a team for the project was really helpful as we would bounce ideas off each other, could talk to each other, and we analysed data better.” Importantly, maintaining these critical partnerships supported collaborative thinking and reflection, which promotes different perspectives and experiences (Murcia, 2005). Cait mentioned the importance of having a critical friend during observations, noting “we would be with a child working with the Beebots or Cubetto and Lauren would see something and pick up on something that I may not have noticed. We would see different things like hearing directional language, while I was focused on what they were doing with the actual Cubetto or Beebot.” Maintaining critical friendships enhanced each individual teacher’s professional development as they shared and learned from experiences. Lauren stated “we shared ideas with the teachers in the other room, which helped us break the task down and understand how to teach the kids. Just sharing different ideas. Working in a team the collaboration was insightful and I learned from my colleagues." Maintaining these collaborative friendships enriched thinking and reflection, enhancing the overall planning cycle (ACECQA, 2020; Murcia, 2005). Lisa mentioned, "you reflect more on your practice because you ask questions about what others are doing. We are really good at questioning each other and thinking about how we can improve on what we are doing and what is really important about the children's use of technology. We also help each other to come up with ideas." Interestingly, throughout the project the teachers developed trusting and supportive relationships with the researcher, exploring a critical friendship from an external source. Emily said "it was exciting to have someone (researcher) from outside the centre come in. We got to show and share how amazing it all was, how much the children learned, and how much we learned from this one little robot. I think it also pushed us to want to do more."

## 3.8 Discussion and Conclusion

This action research project impacted the teachers' knowledge about digital technologies and pedagogy in a number of ways. It was evident that the intentional planning process and shared reflection enhanced their own understanding and ability to meaningfully integrate digital technologies into the children's learning environment. Teachers were increasingly aware of the children's developing digital literacies and better able to develop quality inquiry learning experiences that integrated knowledge and skills across learning areas. For example, Cait said, "the project tools helped me make connections across activities and learning areas, like when we used the inquiry design process to make a house for Cubetto." As the teachers developed their own understanding of coding and computational thinking, they could extend their teaching practices. The teachers were acquiring new pedagogical knowledge for integrating digital technologies into their programs in a meaningful and intentional way which, at the centre was children's learning interests (Carr & Kemmis, 1986; Elliot, 2001).

Prior research has suggested that teachers in the early years sector have not felt sufficiently supported to effectively integrate digital technologies into their curriculums (Zabatiero et al., 2018). However, the structure of this project design allowed the teachers to have the freedom to explore what the integration of digital technologies looked like in their own kindergarten program while being supported by collaborative and collegial reflection. For example, Lauren stated that "the project gave us freedom and support, which was really helpful for myself and our Centre Director." She said, "the project was inspiring because it gave me the space to try something for myself and to be able to feel like I was helping the children to learn about technology." Additionally, Lauren shared "I became a lot more comfortable to share things and speak my mind. I felt more confident working in a team." It was evident that the project had positively impacted the Teacher's overall confidence in integrating digital technologies into their learning and teaching programs. This observation confirmed understandings in research literature; when working in professional partnerships and providing support and opportunities for shared knowledge, teachers develop their digital technology skills and practices (Murcia et al., 2018).

The participating teachers developed a range of digital technology skills as a result of the project, as articulated through the teacher stories and emerging themes. Specifically, the teachers gained confidence and understanding of how to effectively integrate digital technologies into children's play and learning experiences. Through these experiences, the teachers were able to identify the value in certain digital technologies, applying this knowledge to realise other digital technologies that engage young children in active and collaborative digital technology use. As the teachers developed confidence using the digital technologies, they were able to share their knowledge and teach the children the necessary skills to use digital technologies to explore and represent their ideas. Importantly, these skills all correspond to the Australian EYLF Outcome 5.4, where children are able to use digital technologies to access information and represent their ideas (DEEWR, 2009). Through this project, the teachers developed an understanding of the multiple components of digital technologies, including software and hardware. Moreover, the teachers developed an understanding of how patterns in digital technology can be represented as data and were able to develop and shape learning experiences that facilitated these skills. Additionally, the teachers developed an understanding of the algorithms needed to solve problems. Interestingly, these skills are emphasised once children move to full time schooling in Foundation level until year two, though the kindergarten children involved in the project achieved each of these outcomes supported by confident and reflective teachers (ACARA, n.d.)

By participating in this action research project, the teachers developed the confidence and competence necessary for quality integration of digital technologies into their early years service. This confidence underpinned their ability to develop quality digital technology learning experiences and sparked their enthusiasm for further professional learning and growth (Mantilla & Edwards, 2019; NAEYC & Fred Rogers Center for Early Learning and Children's Media, 2012). Critical to the success of the project, the research method aligned with the cycle of planning and hence supported this group of teachers to facilitate inquiry investigations that meaningfully integrated tangible coding technologies and provoked children's cross-curricular learning.

## References

Australian Children's Education & Care Quality Authority [ACECQA]. (2020). *Guide to the national quality framework*. https://www.acecqa.gov.au/sites/default/files/2020-01/Guide-to-the-NQF_2.pdf

Australian Children's Education & Care Quality Authority [ACECQA]. (n.d.—a). *About exceeding*. https://www.acecqa.gov.au/assessment/exceeding-nqs

Australian Children's Education & Care Quality Authority [ACECQA]. (n.d.—b). *About the excellent rating*. https://www.acecqa.gov.au/assessment/excellent-rating

Australian Curriculum, Assessment and Reporting Authority. (n.d.). *Technologies: digital technologies F-2 strand: Digital technologies content descriptors*. https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/digital-technologies
Blackwell, C. K., Lauricella, A. R., & Wartella, E. (2014). Factors influencing digital technology use in early childhood education. *Computers & Education, 77*, 82–90.
Bognar, B., & Zovko, M. (2008). Pupils as action researchers: Improving something important in our lives. *Educational Journal of Living Theories, 1*(1), 1–49.
Borgia, E. T., & Schuler, D. (1996). *Action research in early childhood education.* (ED401047). ERIC. https://files.eric.ed.gov/fulltext/ED401047.pdf
Borgia, E. T., & Schuler, D. (1996). *Action research in early childhood education. ERIC digest.* Retrieved from https://link.library.curtin.edu.au/gw?url=https://www-proquest-com.dbgw.lis.curtin.edu.au/other-sources/action-research-early-childhood-education-eric/docview/62604053/se-2?accountid=10382
Carr, W., & Kemmis, S. (1986). Becoming critical: Education, knowledge and action research. *Routledge*. https://doi.org/10.4324/9780203496626
Chaudron, S., Beutel, M. E., Donoso Navarrete, V., Dreier, M., Fletcher-Watson, B., Heikkilä, A. S., ... & Wölfling, K. (2015). *Young children (0–8) and digital technology: A qualitative exploratory study across seven countries*. JRC; ISPRA
Checkland, P., & Holwell, S. (1998). Action research: Its nature and validity. *Systemic Practice and Action Research, 11*(1), 9–21.
Department of Education, Employment and Workplace Relations [DEEWR]. (2009). *The early years learning framework for Australia: belonging, being & becoming.* http://files.acecqa.gov.au/files/National-Quality-Framework-Resources-Kit/belonging_being_and_becoming_the_early_years_learning_framework_for_aust ralia.pdf
Donohue, C. (Ed.). (2014). *Technology and digital media in the early years: Tools for teaching and learning*. ProQuest Ebook Central. http://ebookcentral.proquest.com
Efron, S. E., & Ravid, R. (2013). *Action research in education : A practical guide.* ProQuest Ebook Central. http://ebookcentral.proquest.com
Efron, S. E., & Ravid, R. (2013). *Action research in education: A practical guide*. Guildford Press.
Glassman, M. (1996). The Argument for constructivism. *American Psychologist, 51*(3), 264–269.
Gummesson, E. (2000). *Qualitative methods in management research* (2nd Ed.). Sage Publications.
Mantilla, A., & Edwards, S. (2019). Digital technology use by and with young children: A systematic review for the statement on young children and digital technologies. *Australasian Journal of Early Childhood, 44*(2), 182–195. https://doi.org/10.1177/1836939119832744
Maternal and Child Health Nurse. (2007). *Reflective practice.* Victoria State Government Education and Training. https://www.education.vic.gov.au/Documents/childhood/professionals/support/all.pdf
Mikelić Preradović, N., Lešin, G., & Šagud, M. (2016). Investigating parents' attitudes towards digital technology use in early childhood: A case study from Croatia. *Informatics in Education, 15*(1), 127–146. https://doi.org/10.15388/infedu.2016.07
Murcia, K. (2005). Using action research principles for professional development: The Waikiki school experience. *ALAR Journal, 10*(1), 3–17.
Murcia, K., Aranda, G., & Campbell, C. (2018). Trends in early childhood education practice and professional learning with digital technologies. *Pedagogika, 68*(3), 249–264. https://doi.org/10.14712/23362189.2018.858
Murcia, K., Pepper, C., Joubert, M., Cross, E., & Wilson, S. (2020). A Framework for identifying and developing children's creative thinking while coding with digital technologies. *IIER, 30*(4), 1395–1417.
Murcia, K., & Tang, K. S. (2019). Exploring the multimodality of young children's coding. *Australian Educational Computing, 34*(1), 1–15.
National Association for the Education of Young Children [NAEYC] & Fred Rogers Center for Early Learning and Children's Media. (2012). Technology and interactive media as tools in early childhood programs serving children from birth through age 8. *Joint position statement*. Washington,

DC: NAEYC; Latrobe, PA: Fred Rogers Center at St. Vincent College. https://www.naeyc.org/sites/default/files/globally-shared/downloads/PDFs/resources/topics/PS_technology_WEB.pdf

Neylon, G. (2015). Professionalising the early childhood education and care sector: Broadening the university mission. *Social Alternatives, 34*(2), 33–38.

Papadakis, S. (2020). Robots and robotics kits for early childhood and first school age. *International Journal of Interactive Mobile Technologies, 14*(18), 34–56.

Polkinghorne, D. E. (1995). Narrative configuration in qualitative analysis. *International Journal of Qualitative Studies in Education, 8*(1), 5–23.

Rout, S., & Behera, S. (2014). Constructivist approach in teacher professional development: An overview. *American Journal of Educational Research, 2*(12), 8–12. https://doi.org/10.12691/education-2-12A-2

Thorpe, K., Hansen, J., Danby, S., Zaki, F. M., Grant, S., Houen, S., Davidson, C, Given, L. M. (2015). Digital access to knowledge in the preschool classroom: Reports from Australia. *Early Childhood Research Quarterly*, *32*, 174–182

Zabatiero, J., Straker, L., Mantilla, A., Edwards, S., & Danby, S. (2018). Young children and digital technology: Australian early childhood education and care sector adults' perspectives. *Australasian Journal of Early Childhood*, *43*(2), 14–22. https://doi.org/10.23965/AJEC.43.2.02

# Chapter 4
# Integration of ICT in Science Education Laboratories by Primary Student Teachers

**Argyris Nipyrakis and Dimitris Stavrou**

**Abstract** Integration of Information and Communication Technologies (ICT), such as datalogging systems in science teaching laboratories has a long-standing and ongoing history. However, teachers' views and practices should be examined in order to achieve higher levels of efficacy and meaningful implementation of ICT in schools. In the present study, 12 primary student teachers along with an expert design and develop lab teaching material by implementing datalogging systems. The extend to which they integrate datalogging, as well as the nature of integration of ICT that they adopt is been studied through qualitative analysis of group discussions and quantitative analysis of the science experiments developed. Findings of the study reveal that student teachers addressed difficulties in 'actively' integrating technology in a non-negligible amount of experiments, not only due to lack of content and technological content knowledge needed, but also due to cultural incompatibilities with the innovative and student-centered affordances of datalogging. Student teachers also held limited views of technology and regarded dataloggers mostly as measurement tools and not as a tool for inquiry. Moreover, student teachers' prior experiences on using ICT as well as their prime emphasis on PCK strongly affected the design of experiments, indicating a PCK to TPACK approach.

**Keywords** Technology integration · Teachers' views · Datalogging

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## 4.1 Introduction

Practical work, i.e. experiences in school settings in which students interact with equipment and materials or secondary sources of data to observe and understand the physical world (Hofstein et al., 2013) has traditionally been a distinctive goal in science education (NRC, 2012) due to the multiple benefits that it offers. Increased students' motivation and interest, development of better understanding on scientific concepts, development of science inquiry skills and perceptions of nature of science (Hofstein et al., 2013) are some of them. Moreover, the science laboratory has always been a fruitful context for integrating contemporary technological tools, in order to increase learning gains, but also in cultivating practical and technological skills (Sokoloff et al., 2007).

In fact, technology has always been interconnected with science in authentic scientific practices. Hence, educational reforms during the 80s and 90s which aimed to the assimilation of scientific practices in schools (NRC, 1996) high valued the integration of technological tools in the school laboratory. Since then, technology has increased rapidly, and technological tools with innovative features and usability have 'invaded' science education. Therefore, integrating technology in science education kept been a long-standing and continuous goal for researchers whilst several calls strive for effectively implementing Information and Communications Technologies (ICT) in education (Waight & Neumann, 2020). Similarly, in recent Integrated STEM approaches i.e. teaching approaches in which students are encouraged to understand and develop interconnections between STEM disciplines (Martín-Páez et al., 2019), integrating technology is an issue of high importance.

However, successful enactment of technology in schools is still an ongoing and complex endeavour, since several parameters of the classroom 'ecosystem' i.e. teacher, students, context, should be taken into account (Waight & Abd-El-Khalick, 2012). Specifically, the role of the teacher is regarded as a determining agent of the effective adoption of the educational innovation of ICT, since his understandings and beliefs highly affect the meaningful integration of ICT (Ertmer & Ottenbreit-Leftwich, 2013; Juuti et al., 2016). Therefore, it is imperative to study teachers' views and practices on implementing technology, the difficulties that they encounter, as well as the interaction with the other elements of the ecosystem. Moreover, it is of additional value to focus on preservice teachers' views and practices on implementing technology in order to develop informed preservice teacher training programmes that will prepare future generations of teachers able to make meaningful use of the affordances of the ICT tools.

### *4.1.1 Datalogging Systems*

In the present study, ICT tools used in the school laboratory relate to datalogging systems, also known as Microcomputer-Based Laboratory (MBL) systems or computer-aided practical work. In specific, datalogging systems consist of: (i) electronic sensors (wired/wireless), (ii) data collection and analysis devices, such as computers or more recently, portable "smart" devices as tablets, smartphones and (iii) the appropriate data collection and analysis software (Ye et al., 2019). Their main affordance is that data can be collected and represented in real-time; hence, the visualisation of phenomena can contribute to increased students' understanding (Donnelly-Hermosillo et al., 2020). By using datalogging systems, students can study relations between variables easily and avoid time-consuming procedures (Barton, 2005), and they are supported to conduct their own investigations that are difficult to achieve without technology (Donnelly-Hermosillo et al., 2020). Furthermore, students are given the chance to cultivate laboratory skills, such as selecting variables, materials, methods and tolerated experimental errors (Chen et al., 2014), as well as to improve their graph skills and to use dataloggers for predicting the evolution of the experiment, contributing to inquiry-based approaches (Nicolaou et al., 2007; Sokoloff, 2017).

Using dataloggers can also contribute to improvement of students' modelling and symbolic language skills (Bisdikian & Psillos, 2002; Liu et al., 2017; Wong, Chen, et al., 2020; Ye et al., 2019) by connecting the underlying mathematical modeling with the related phenomena and therefore, integrating theory with practice (Lavonen et al., 2003; Sokoloff et al., 2007), by using multiple modalities: both concrete and abstract/mathematical (Ye et al., 2019). Therefore, datalogging systems can additionally promote the cultivation of interdisciplinary thinking and skills to students (Wong, Quast, et al., 2020).

Using datalogging also reduces time for data collection and procedural tasks and results in the quick repetition of the experiments in order for the students to concentrate on the underlying concepts and discuss on them (Chen et al., 2014; Nicolaou et al., 2007; Tortosa, 2012). Moreover, a wider range of experiments may be performed, as well as the fact that some experiments may be performed with more safety in comparison with conventional laboratory settings and manipulation of hazardous materials (Barton, 2005; Tortosa, 2012).

Further technological advances on dataloggers have also resulted in innovations, such as the portability of dataloggers, which may extend the capabilities for science and mathematics education by concurrently reducing the high cost of the equipment without reducing the level of precision on data collection (Liu et al., 2017). Concurrently, attitudinal benefits also arise, since using datalogging can motivate students (Chen et al., 2014; Wong et al., Wong, Quast, et al., 2020, Wong, Chen, et al., 2020), including students from minority groups or students with educational disabilities (Barton, 2005).

### *4.1.2 Technology Integration*

Regardless of the potentialities that innovative ICT tools offer, technology integration is to a great extent context-specific, and in many cases it may turn to be problematic.

Particularly, the act of integrating ICT does not necessarily promote inquiry-based learning and increased student science achievement, whilst in some cases it can restrict it (Odom et al., 2011; Waight & Abd-El-Khalick, 2007). Hence, it is imperative to study the factors affecting the successful implementation of ICT in order to achieve efficacy. Under this prism, (a) teacher's knowledge and attitudes towards technology, (b) the classroom contextual environment and pedagogy, as well as (c) the features and usability of ICT tools themselves should be taken seriously under consideration when integrating ICT.

First, the role of the teacher has far been stressed as crucial, since he is regarded as the important agent of the educational innovation, such as ICT (Juuti et al., 2016; Lavonen et al., 2003). In specific, teacher's technological knowledge (Ifinedo et al., 2020) as well as teacher's beliefs and attitudes in using technology (Farjon et al., 2019; Prestridge, 2017) are stated as defining factors for technology integration in schools.

Considering teacher's knowledge for science teaching, the Pedagogical Content Knowledge (PCK) framework has long been used in teacher education as both: (a) a knowledge base used in planning for and the delivery of topic-specific instruction in specific classroom contexts and (b) a skill, the act of teaching that occurs in the specific content and classroom context. Furthermore, in recent updates of the framework, topic-specific professional knowledge is defined as the canonical knowledge needed to teach specific topics according to specific students' developmental level. Particularly, topic-specific professional knowledge is characterised as relatively static, visible and related to public understanding held by the community in contrast to PCK which is more dynamic and personal knowledge. Moreover, topic-specific professional knowledge interacts with 'teacher professional knowledge bases', such as Pedagogical knowledge, knowledge of assessment, content, curriculum and students. Subsequently, the teacher's topic specific professional knowledge is been affected by teacher amplifiers and filters, i.e. teacher's prior knowledge, beliefs and attitudes in order to be transformed to PCK applied during the classroom practice (Gess-Newsome, 2015).

Similarly, in the field of technology integration, the Technological Pedagogical Content Knowledge (TPACK) is the form of knowledge needed in order to effectively teach science content with the use of ICT and derives from the combination of Technology, Pedagogy and Content knowledge. Additional subordinate intersections of knowledge domains are also defined as: (a) Technological Content Knowledge (TCK), which is knowledge on how science and technology influence and constrain one another, e.g. restrictions but also affordances that technology offers in representations of content as well as how the content dictates or even changes the technology used, and (b) Technological Pedagogical Knowledge (TPK), which is knowledge on existence, components and capabilities of various technologies as used in teaching and learning settings as well as how teaching can be affected by using these technologies (Koehler et al., 2013).

Second, the context and the pedagogy that ICT are used, affects the learning gains from using ICT in classrooms. Often, even when teachers use ICT in the classroom, they do not tend to make efficient use of them. Teachers tend to use ICT in a "passive" way, e.g. for presentations, reading texts and completing worksheets, which do not seem to improve student achievement (Odom et al., 2011; Papanastasiou et al., 2003). The same occurs with early-career teachers that, even though they feel confident about their skills in using ICT, they restrict the use of ICT in lesson preparation (word processing) and mail communication and not in the science classroom, where research shows great potential for student learning (Dawson, 2008). The above practices rather reflect traditional teacher-centered practices and do not improve students learning, nor they promote inquiry (Odom et al., 2011; Prestridge, 2017; Waight & Abd-El-Khalick, 2007). On the contrary, when ICT are been used in a student-centered pedagogy, with the active participation of the learner and following an inquiry stance, results are positive (Ertmer & Ottenbreit-Leftwich, 2013; Odom et al., 2011; Waight & Abd-El-Khalick, 2018; Zucker et al., 2008). For example, particularly using MBL with an emphasis on observation and prediction, as well as for taking into account students' alternative ideas contributes substantially to students' learning with Technology (Bisdikian & Psillos, 2002).

Furthermore, embedding ICT in an authentic and social context, in which participants are encouraged to collaborate and interact reflectively in authentic science contexts *for* science learning assists them to integrate ICT meaningfully (Bell et al., 2013; Iliaki et al., 2019). Moreover, contextual factors regarding the high costs of MBL still hinder implementation of MBL (Tortosa, 2012), even though new generation of cost-effective devices tend to solve this problem (Liu et al., 2017).

Finally, concerning ICT tools and their innovative features, their effectiveness and usability in relation to the general ecological factors (teachers and students' knowledge, attitudes and culture, general context) should be examined. In specific, many technologies used in schools are not primarily designed under an educational perspective. For example, some word processing software were designed for business purposes, whilst some web-based technologies e.g. blogs and pod-cast are made for entertainment, communication and social networking purposes (Koehler et al., 2013). Therefore, when implementing a technology, it is imperative to consider the purposes, culture and values that they represent comparing to the ones that are needed in the system to be implemented, i.e. the school and teacher culture, beliefs, knowledge and expertise (Waight & Abd-El-Khalick, 2018; Waight & Neumann, 2020). Hence, recent updates of the TPACK model also incorporate contextual knowledge, as well as interactions with culture and organisations in a more systemic approach (Mishra, 2019; Warr et al., 2019).

### *4.1.3 Aim of the Study*

Therefore, the present study investigates the integration of technology in the science laboratory by primary student teachers. Student teachers work in groups in a science teaching laboratory in order to design and develop science experiments with the use of datalogging systems. Furthermore, student teachers collaborate with peers in order to reflect on the design of the experiments and the use of dataloggers on the experiments. Subsequently, they implement them for science teaching to school students.

In specific, the study investigates the extent to which primary student teachers integrate ICT when designing laboratory teaching material as well as the nature of technology integration, in terms of active/passive use of ICT, implementation of innovative features such as using datalogging systems for prediction/inquiry processes and portability. Furthermore, analysis of student teacher discussions about their developed teaching material aims to shedding light on their views and deficiencies towards technology integration. Therefore, the research questions are:

- How do primary student teachers integrate datalogging in order to design and develop science laboratory teaching material?
- What difficulties do they encounter when designing and developing science laboratory teaching material with the use of datalogging?

## 4.2 Theoretical Framework

Theoretical framework of the present study is the Model of Educational Reconstruction for Teacher Education (Van Dijk & Kattmann, 2007), modified and adapted to the needs of the present study. The general characteristic of the model is trying to bring science-related issues and educationally-oriented issues into balance, whilst it addresses the gap between science education research and science instruction practice (Duit et al., 2012). According to the model, the following five elements interact dynamically: (a) First, the clarification of the subject matter, the analysis of its educational significance and the reconstruction of the science content by taking into consideration students' misconceptions and interests, science processes and views on nature of science. In addition, in the context of technology integration, we consider imperative to also examine the technological innovations as well i.e. their features and usability for their educational significance and purpose in the context of science education. The reasoning behind such an approach is that, according to researchers of philosophy and nature of technology, technological advances in school classrooms often follow a faith-based approach and often neglect the 'baggage' that these technologies bring along, such as "the specific purposes, context, knowledge and expertise of the specialized agents, culture and values as well as financial, professional and social structures that ushered and nurtured the use and adoption of these technologies" (Waight & Abd-El-Khalick, 2018). Therefore, the ICT tools, i.e. their features and use should also be analysed and reconstructed in order to meet educational needs of science education. (b) Empirical studies on students' misconceptions and interests, teachers' views and beliefs of the science concepts and students' learning as well as teaching and learning processes and the role of instructional tools, in our case dataloggers. Furthermore, studies about students' learning with the use of technology as well as students' attitudes and views on technology should be taken into account in order to maximise the effectiveness in integrating technology for science learning. (c) The design and evaluation of learning environments,

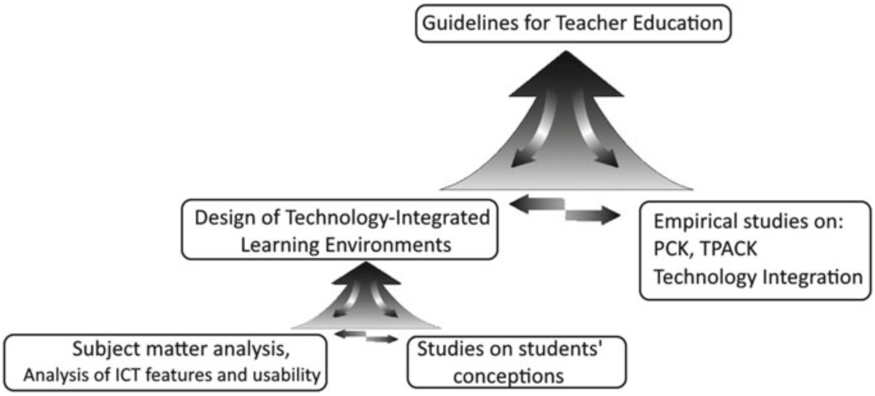


**Fig. 4.1** Model of Educational Reconstruction for Teacher Education (Van Dijk & Kattmann, 2007), as modified and adapted to the needs of the present study

which in our case refer to technology-integrated learning environments, in continuous and dynamic interrelation with the aforementioned two elements. (d) Studies about teachers' PCK, their knowledge, beliefs and experiences, along with technology integration and TPACK studies in the present study, the knowledge needed to effectively teach science content with the use of technology. (e) The design and the production of guidelines for teacher education programmes, which in the present study refers to technology-integrated teacher education programmes.

Therefore, the central aspects of the presented model shown in Fig. 4.1 is that it gives emphasis on the educational reconstruction of the subject matter, empirical studies on teaching and learning as well as the examination of how technology facilitates science learning.

## 4.3 Method

The study was carried out during an undergraduate science laboratory course and lasted one academic semester, i.e. 13 weeks. Participants were 12 female student teachers during their 4th year of studies at a primary education academic department. The student teachers had previously attended a science content course about introductory science content knowledge, a science teaching methodology course and a course about general use of educational technology, e.g. using software for developing activities and quizzes, developing a webpage etc. However, they had no previous training on datalogging systems or using other ICT tools specifically in the context of the science laboratory. As related to the Greek primary educational system, it is highly recommended, albeit not mandatory, for graduated primary teachers to implement ICT in classroom and cultivate ICT-related skills to students. Hence, this course is part of the courses that student teachers may assign to in order to develop their digital competences.

The student teachers formed small groups of two, whilst all six student teacher groups formed a Learning Community (LC) (Couso, 2016), together with a science education researcher. The researcher played the role of the expert in the domains of science, school laboratory and ICT during the LC meetings, whilst during the lab sessions his role was marginalised, since he provided assistance mostly on technical/procedural issues. For the needs of this paper, student teacher groups are represented with a number (1–6), whilst each student teacher was additionally assigned with the letter a or b, e.g. 6a represents a student teacher in group 6. Similarly, the researcher was represented as R.

The course consisted of an introductory phase, three design phases and an implementation phase, as shown in Fig. 4.2. The introductory phase lasted two weeks and included both a classroom lecture and a lab session about datalogging and laboratory equipment, in which student teachers got acquainted with sensors and basic features of dataloggers, such as connectivity, real-time data collection and various representations of data (graph/digits/meter). Subsequently, each design phase lasted two weeks and comprised two weekly lab sessions (3 h each). In this phase, student teachers were called upon to design and develop teaching material, i.e. science experiments and indicative worksheets with the use of datalogging in six branches of Science: Mechanics, Waves/Oscillations, Optics, Electromagnetism, Thermodynamics and Chemistry. After the completion of each design phase, there was a cyclical swift of the branches of science between the student teacher groups. Furthermore, in order to give emphasis to inquiry-based teaching, student teacher groups were called upon to submit a bibliographic review of students' alternative ideas in the specific branch of science they were assigned in the beginning of each design phase. Finally, during the implementation phase, the student teachers applied the developed teaching material in teaching school students during educational school visits in the university science teaching laboratory.

Importantly, in order to support collaboration between peers and expert guidance, an LC meeting was held between the design phases, in terms of reflection on student teachers' practice and additionally, in providing feedback and ideas for the subsequent design phases. A final reflective LC meeting was also held for the student teachers to share their overall experience and views about integrating ICT in the school laboratory.

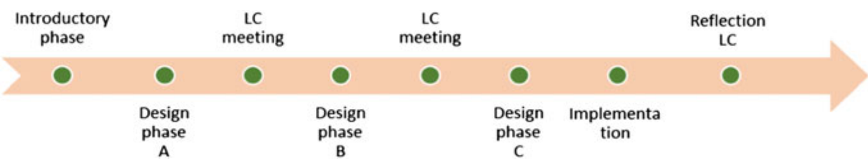


**Fig. 4.2** Implementation of the study

### *4.3.1 ICT Tools*

In the present study, considerations of technology are specifically referred to the digital age and within the educational context. In particular, student teachers were called upon to integrate ICT tools, such as datalogging systems. Datalogging systems of the study consist of Pasco (www.pasco.com) sensors (wireless/wired) along with data collection and analysis devices (tablets/laptops/smart devices), in which the appropriate data analysis software is installed, Pasco Sparkvue in specific. However, student teachers improvised in some cases by using real-time datalogging through their smartphone applications, e.g. DaTuner Lite.

### *4.3.2 Data Collection and Analysis*

Data was gathered during the academic semester that the course was implemented through: (a) the developed teaching material i.e. science experiments, as presented through the powerpoint presentations in the LC meetings, indicative worksheets and lab reports, (b) transcribed discussions during the LC meetings, (c) researcher's field notes about student teachers' ICT integration practice during the lab sessions for triangulation, (d) initial questionnaire about the student teachers' views and attitudes concerning ICT and experimentation.

Integration of technology in the developed teaching material was analysed in two levels: First, the extent to which student teachers managed to integrate datalogging and/or ICT in general in the design of science experiments. Second, the use of datalogging was further analysed, in terms of: (i) whether datalogging were used in a meaningful or procedural way, i.e. whether using datalogging for data collection and analysis assisted the completion of teaching goals or whether they were integrated "passively"/in a procedural way, without offering an additional value to the design of the experiment, respectively, (ii) whether datalogging tools were also used for inquiry purposes, such as to predict students' misconceptions. In particular, dataloggers had a feature that offered the students the opportunity to draw the evolution of the physical value in the graph, so that they could subsequently interpret and compare the results with their predictions, (iii) whether student teachers made meaningful use of innovative features of the tools, such as the portability of the sensors/devices in this case.

For the needs of the analysis, the developed teaching material was initially analysed and triangulated through several sources i.e. descriptions in the LC/presentations/worksheets/lab reports, and a matrix of science experiments ($n = 90$) was created in SPSS software. Each of the experiments was coded across several binary variables declaring the existence of absence of this category/feature, while the design phase was coded as ordinal variable. Due to the nature of the variables, non-parametric K independent samples Kruskal–Wallis tests were used among the design phases, as well as between student teacher groups.

Moreover, in order to gain more in-depth insights about student teachers' views and attitudes towards integration of ICT, qualitative content analysis (Mayring, 2015) of student teachers' discussions in the LC meetings was carried out. In specific, themes derived from discussions that were made during the LC meetings and were related to the research questions, i.e. their views and difficulties on integrating technology, were initially identified inductively. Subsequently, the themes were re-analysed and grouped in regard to the issue involved and hence, inferences were produced inductively. Additionally, characteristic typologies that represent extreme or important statements according to the literature were also took under consideration. Furthermore, data from student teachers' discussions were also analysed in the light of the results from the quantitative analysis in order to increase validity.

## 4.4 Results

### *4.4.1 Integration of ICT*

In relation to the total number of developed experiments, student teachers managed to integrate dataloggers in the majority of the experiments (n = 56), as shown in Fig. 4.3, whilst in some cases (n = 5) ICT tools were used, but not in the context of datalogging, e.g. use of video recording and editing in fast forward mode or lab instruments with digital measuring, such as a four-digits scale.

Hence, we can see in Fig. 4.3 that despite the predefined goal of integrating ICT in the experiments, in a non-negligible amount of experiments integrating ICT was not made possible. In an effort to interpret this difficulty, we can see from the analysis of student teachers' reflections that non prior experience with datalogging, as well as lack of TCK on how to use datalogging acted as hindering factors for the integration of ICT. Noteworthily, these deficiencies do not refer to using educational technology in general—since student teachers had previous academic training in using general ICT tools and software in education, but it is rather referred specifically to using datalogging systems actively in the school laboratory, which seems to require a different skillset.

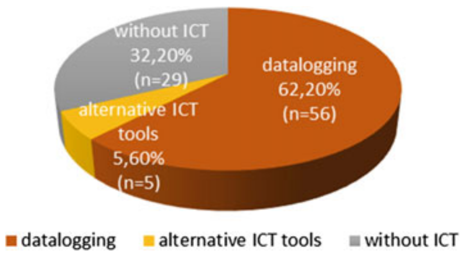


**Fig. 4.3** Integration ratio of ICT in the experiments

Student teachers also stated shortage in CK as impeding factor for the design of ICT-rich experiments. Moreover, they also expressed several concerns on understanding some specific topics or branches of science that indisputably affected the design process and implementation of ICT, according to their reflections.

5b: Electromagnetism. In general, I don't get along well with Physics.
R: you mean the content?
5b: yes, the content, it was difficult for me as a branch of science. I mean, if I didn't have, if I had to do it my own, I wouldn't had made it.
2b: Yes, I faced great difficulty in the experiments that we had to develop for Chemistry in specific. In the others I had no problem.

The above reflections indicate deficiencies in the context of specific content topics, which denotes the impact of Topic-Specific Professional Knowledge (Gess-Newsome, 2015) in the present study. However, it seems that in some cases the topics did not only affect the general design of the experiment, i.e. PCK, but also specifically affected the integration of ICT as well.

6a: Optics was difficult also for the integration of ICT.
R: As content? What exactly do you mean?
6a: for the ICT as well […].
6b: we couldn't find how to integrate ICT […] The kids were bored with the spectrometer […] It is a different thing to try with the prism to make a rainbow and different thing with the spectrometer in which we expect the result from the tablet.

It seems that the specific content concepts and representations also affected the integration process of ICT, in a similar way that they affect the development of PCK (Gess-Newsome, 2015). Noteworthy is also the fact that divergence was noted about which topics student teachers addressed most difficulties, as different student teachers stated different topics/branches of science that they addressed problems, which could be interpreted by diverse levels of knowledge, experiences and previous representations in these topics that each teacher had. The above divergencies among student teachers indicate both the complexity and the specificity of the task of integrating ICT in the context of teaching science content, i.e. developing TPACK.

Moreover, we can see from the above quotations of 6b that another impeding factor is apparent, which is more related to their attitudes and views about ICT, as also commented below:

5a: Because I interact with little kids, I have nephews and I see that many things that I try to explain to them, they understand it more easily if I show them simple things, if I tell them simply, not so sophisticated.
5b: it has to do with the age I think.
3b: I believe that as younger they are, the better is to use simpler materials in order to relate them with their everyday life.
4a and we couldn't find, I mean the experiments that I did in primary school was far more simple.

4b with candles.
4a with candles, with torches, means something that you couldn't integrate tablets for sure.

In specific, 5 student teachers seemed to hold quite conservative views about little kids' familiarity with technology and they emphasised using 'simple' i.e. non-digital instructional materials from students' everyday life as more comprehensible for younger kids. On the other hand, this view neglects the contemporary routine of little kids which is surrounded by digital technologies, as well as the ICT skills that kids develop from their daily interaction with ICT tools. There seemed to be an incompatibility of views on what is regarded as familiar for kids today. This 'generation gap' (Prensky, 2001) between digital 'immigrants' and 'natives' seem to have influenced student teachers' views about ICT, their applicability and affordances for kids education. Therefore, we consider reasonable to hypothesise that this hierarchy of status between 'simple' instructional materials and ICT tools had also impacted the integration ratio of ICT. In addition, as made clear from the above statements, student teachers' previous experiences either as students themselves or as practitioner teachers with simple instructional materials tended to influence their views on the implementation of ICT.

Consequently, we can see from the above quotations of 6b, 5a, 3b that student teachers' personal amplifiers and filters i.e. their prior representations, experiences and knowledge as well as beliefs and attitudes towards ICT should also been taken under consideration, since they may also affect the development of TPACK knowledge by facilitating or impeding the integration of ICT in the teaching material, in the same way that they affect the development of PCK (Gess-Newsome, 2015). In this light, we can identify not only content-specific difficulties but also difficulties related to personal culture and values about technology (Waight & Abd-El-Khalick, 2018).

Furthermore, analysing the evolution of the integration ratio of ICT per design phase, we can see in Fig. 4.4 that the integration ratio of MBL remained considerably the same among the three design phases (p = 0,936). However, student teachers stressed that there was an increasing difficulty in later phases in designing non-trivial experiments in relation to the ones that their peers had already designed in

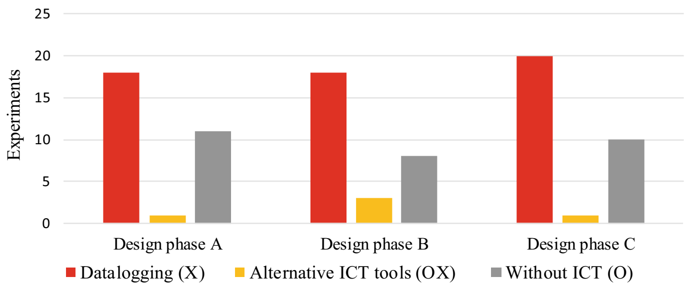


**Fig. 4.4** Integration of ICT according to design phase

previous design phases. Hence, preserving integration ratio in similar levels could be interpreted as a successful endeavour, in which collaboration between peers played an important role, as has been analysed in previous work (Nipyrakis & Stavrou, 2019).

### 4.4.2 Use of ICT in the Experiments

Further analysis concerning the use of datalogging implemented by student teachers in the experiments, reveals that in 14% of the experiments, datalogging was used passively/in a rather procedural manner, as shown in Table 4.1. That means that ICT were integrated as an external task without meaningfully contributing to the accomplishment of the teaching goals of the experiment. For example, a student teacher group used a sound intensity sensor in an experiment where the goal was to show that sound waves cause oscillation in the materials that they are transmitted, e.g. in sugar grains over a speaker.

Student teachers' reflections in the LC meetings also confirm this passive use of ICT, as stated below:

> 6a: In some cases it [technology] was necessary for sure, but there are others that you were saying let's put that so that it exists.
> 5b: just add a prediction.
> 6a: Let's add a sound sensor so that it is there, so I did.
> 5b: […] In the first phase about Chemistry, actually we used it [technology] for measuring. Then in Thermodynamics we also had it for comparing and predicting [data]. In Electromagnetism also measuring and predicting.
> R: That is important right? That many of you used it [technology] just for measuring or using it for measuring that it was not actually needed, I mean it was not necessary.
> 6a: yes but we should do something about it.
> 5b: yes, that said, we should integrate.

**Table 4.1** Use of datalogging in the experiments

| | Experiments | % of total experiments with dataloggers |
|---|---|---|
| Meaningful/'active' use of datalogging | 48 | 85.7 |
| Procedural/'passive' use of datalogging | 8 | 14.3 |
| Using datalogging for prediction of students' views | 8 | 14.3 |
| Use of portability | 3 | 5.4 |
| Total sum of experiments | 56 | |

**Table 4.2** Use of datalogging per design phase

| | Phase A | Phase B | Phase C | Total |
|---|---|---|---|---|
| Meaningful/'active' use of datalogging | 17<br>94.4% | 14<br>77.8% | 17<br>85.0% | 48<br>85.7% |
| Procedural/'passive' use of datalogging | 1<br>5.6% | 4<br>22.2% | 3<br>15.0% | 8<br>14.3% |
| Using datalogging for prediction of students' views | 0<br>0.0% | 4<br>22.2% | 4<br>20.0% | 8<br>14.3% |
| Use of portability | 1<br>5.6% | 1<br>5.6% | 1<br>5.0% | 3<br>5.4% |
| Total sum of experiments | 18 | 18 | 20 | 56 |

In many cases, ICT came as an external obligation that did not contribute to meaning-making or the experimental procedure, but just fulfilled the task of the course. Moreover, as shown in Table 4.2, this percentage of 'passive' use of datalogging was not reduced, albeit the reflections and the discussions that took place during the LC meetings. On the contrary, the cases of passive use of datalogging increased ($p = 0,367$), since complexity rose in latter design phases due to developing non-trivial experiments already designed by peer groups, as mentioned previously. In order to address this increasing difficulty in latter design phases, increased demands of TCK appeared, which in a non-negligible number of cases resulted to ineffective and procedural integration of ICT.

As related to the usability of features of dataloggers, using dataloggers as an inquiry tool through the prediction of the graph feature, i.e. making use of the touch screen to anticipate the evolution of this physical magnitude, was implemented to a limited extent (14,3%). Student teachers stressed the importance of previous explicit training on specific features of datalogging in order to integrate it in the design. However, albeit the extended discussions in the LC meetings about this feature, it was not given serious attention in the production of the teaching material in the subsequent phases ($p = 0.113$). That doesn't mean that student teachers did not use the inquiry phases of engage and prediction of students' alternative ideas in their worksheets, but they usually did that without the use of datalogging or by misjudging the use of datalogging, e.g. one teacher group initially thought that students could draw the path of the light beam in the tablet, which was not a feature of the specific datalogger systems. In general, we can infer from the discussions that student teachers regarded datalogging systems mostly as a tool for measuring data and not as an integral tool of the inquiry procedure.

Similarly, making productive use of the advances that the portability feature offered was quite restricted (5.4%). Student teachers did used wireless devices (sensors/tablets), but they rarely made meaningful use of the fact that they were portable, in order to facilitate a wider range of experiments or further modify the experiments made. Although several ideas for making use of the wireless nature of sensors and devices were discussed in the LC meetings, e.g. using sound/temperature sensors in sealed objects or underwater or using motion sensors for out-of-class environments, student teachers did not make use of that innovative feature. We could interpret this result in two ways: first, we could hypothesise that implementation of this feature requires higher levels of expertise i.e. TPACK and second, this feature might haven't gained high status from the student teachers under a static traditional indoor lab infrastructure setting. However, this finding contradicts the fact that young people do use a vast range of portable devices in their everyday routine, which implies that implementing these technologies for teaching requires additional levels of TPACK. Further research on teachers' implementation of this innovation is required in order to shed light on its potentiality in lab and out-of-class environments.

### *4.4.3 Developing TPACK*

Analysis of the discussions that took place during the LC meetings also shed light to insights about the process of developing TPACK that the student teachers followed. In specific, answering the question posed in the final LC meeting: 'which factors did you take under consideration when designing your teaching material?', almost all student teacher groups (n = 5 out of 6) in their presentations placed main emphasis and primary hierarchical order on pedagogical issues e.g. student misconceptions, the age and level of students and teaching method and so did mentioned most student teachers (n = 9) in the LC discussion as well. This result is rational, since it reflects their agency as primary teachers.

Moreover, from statements of 8 student teachers we can infer that integrating ICT was rather a subsequent process, since their first goal was to find experiments on that domain or experiments based on students' misconceptions.

> 4b: Initially, it was difficult to find an experiment. Because ok, we should study the content, get into the spirit. Then we used to find the experiment. The second difficulty was how to integrate datalogging, I mean tablet and sensors, so that it would be an experiment with the use of technology. That restricted us a lot, because many times we used to find very nice and comprehensible experiments for the kids, but we rejected them because we couldn't integrate datalogging for example.
> 4a: integrate datalogging.
> 3b: now, about what we were taking under consideration. First what students believe…In this direction we developed experiments, because we had found other experiments but we didn't know on what (misconceptions) they were based on.

Most student teachers gave initial focus on finding experiments that would address content and pedagogical goals, i.e. PCK, while integrating Technology was an additional feature that would be integrated—if possible—in a later stage. It seems that most student teachers followed a developing TPACK process starting with existing PCK before introducing Technology to experiments. However, exceptions did take place, since one group of student teachers high valued the integration of ICT to the classroom context and hence, we can infer that they followed a TPK to TPACK process, as made clear in the below statement.

2a So, the first thing we worried about was to be able to somehow integrate New Technologies and to fit with the age of K-5 and K-6.

However, the general tendency for most student teachers was that ICT was an additional implementation to the experiment, not the primary goal. According to their reflections, the process was to find an experiment primarily addressing pedagogical and content issues and subsequently—if possible, to integrate ICT.

Therefore, a PCK to TPACK model (Koehler et al. 2014) prevailed. Moreover, student teachers tended to return in their previous PCK when they faced difficulties or reached a dead end in implementing technology. These findings are also reflected by the considerable percentages of experiments without ICT and their reflections about the cases that they didn't manage to integrate ICT. Outputs seem to extent the results of similar studies concerning in-service teachers, where it is claimed that prior beliefs on how content should be taught and learned limited the integration of technology (Niess et al., 2010).

### *4.4.4 Views on Technology*

In an effort to further investigate the impeding factors for technology integration, it is worthwhile to further analyse student teachers' views on technology in regard to their reflections during the LC meetings. First, as concerns to their training of skills and knowledge on using ICT, almost all student teachers (n = 11) claimed that they preferred to be trained to technological applications and features in a rather traditional way, so that knowledge about using ICT should be previously shown to them extensively by the trainer in an explicit way.

2a: in general, maybe, in the first lab that you gave us the tools and said search, try, do things with them, that it should be a little like —not more theoretical, I mean that you showed us the way, because we didn't have any experience with these. So you could tell us there are these features and these and then we tried to apply them.
6b: in a more traditional way.
3b: Shall I suggest something? You could, the first week that we got to know the lab, the tablets and physics from this point of view, we could get to know tablets better, know the potentialities they have and to have prearranged some content units and to have somehow a preliminary plan of the experiments, so that we come here and say: are these things correct? Should we proceed and apply them?

On the contrary, the nature of integrating technological tools requires more practical skills and effort that derives from experiencing ICT tools, exploring their use in specific and diverse experimental contexts, as well as dealing with open-ended problems. Hence, a 'cultural lag' appeared between student teachers and the technological context. In specific, the course included an initial training phase in which only basic features were shown e.g. wired/wireless connectivity, datalogging, various data display methods, and subsequently gave the student teachers time and tools to further explore their use with the assistance of teaching assistants, also in out-of-programme hours. This rather constructivist approach about the use of dataloggers that demanded personal-driven engagement was not identified as productive for student teachers, whilst there were also requests for additional training before they try to integrate ICT.

Similar approach was preferred for the design of experiments from most student teachers (n = 10). The open-ended design procedure caused uncertainty to them regarding content knowledge and experimental procedure issues, which were stated as important obstacles.

> 3b: […] I believe that it would be better to discuss them before we make the experiments.
> R: Yes but we wanted you to do them first and then reflect on them and then let's say to revisit them.
> 3b: Yes but, we would see before which things from what we designed were correct anyway and then to try to apply them and create them and ok. In a reflection meeting like this now we would just discuss that, you know, it is fine, while, if we knew it from before, we would say I will do that and that. Are they correct? Yes. Should I implement technology? Yes.
> 4a: You could give us some sources, like take the K-5 school book and look that, for example, waves are taught like this.
> 5b: from there (book), find experiments and make some.
> 4b: evolve them.
> R2: […] So just because physics teachers in school know what is correct, does that mean that you learned what is correct?
> 2b: That is the problem, in my opinion, that we are trained in a culture and when we try to do something much different, we need to have a level of certainty on us and so we got difficulties.

Consequently, the constructivist student-centered setting of designing ICT-rich experiments was found demanding for both designing science experiments and technology integration since student teachers were seeking for a priori instruction and materials from the expert. Important is, however, that both content, procedural and technology knowledge was shared during LC meetings in a rather participatory approach, the expert included. Similarly, discussions in LC meetings also focused on how to combine these domains for the design of teaching material, as well as about the implementation of technological features, like using dataloggers for prediction or using portability, as mentioned previously. However, obstacles in designing technology-rich experiments seemed to be more deep and cultural. It was the traditional educational culture towards adopting educational innovations that was opposed to the student-centered context of designing ICT-rich experiments that hindered the implementation of technology.

Furthermore, an additional factor that dissuaded student teachers from further exploring the datalogging tools was the insecurity they felt in manipulating of the tools. In specific, 5 student teachers mentioned that they were afraid of the possibility of damaging the ICT tools and that that fear restricted them in further exploring the tools. Especially when one group addressed a problem with a damage on a tablet device, they stated that that made them more cautious afterwards. Problems also occurred when student teachers were experiencing unexpected results due to malfunction of the ICT tools or datalogging errors. 6 student teachers mentioned that issues like these distracted them and made them feel confused. On the contrary, it is a common practice to deal with ICT tools or lab instruments to experience damage, malfunction or error. Once more, there was a cultural incompatibility that made student teachers act more unwillingly and conservatively against integrating and using ICT. Therefore, the above insights constitute—among others—to what we could name as 'personal amplifiers and barriers' for cultivating TPACK, is a similar way with that Gess-Newsome (2015) describes as teachers' amplifiers and filters for PCK.

An interesting view about ICT also appeared in student teachers' reflections about their teaching practice with MBL.

> 6b: It makes sense, even we, when we get in the lab that everything is unfamiliar to us, that we see something we haven't seen before, and someone tells us: watch this tablet,—tablets we already have at home and all kids see that, it is normal that they look around and want to explore. Even we, when we got into the lab we were looking around what is this bar, what is this tap, what is.
> R: Yes, why?
> 5b: because it was unfamiliar to us.
> 3b: and they were watching the tablet and they were thinking that we would do, we would listen to music and we will watch youtube with […].
> 2a: youtube basically.
> R: so in these cases their interest was disengaged?
> 3a: yes.
> 3b: yes, it depends from the relation they have with these.

According to student teachers, school students do not primarily regard technological tools as educational tools, but they rather interpret the use of these devices for other purposes related to their everyday use e.g. for amusement—at least in first sight. Hence, student teachers addressed difficulty to relate the use of ICT tools with a teaching goal and to draw students' interest to ICT tools when compared with lab equipment—which in contrary was quite new and more interesting for them. The same occurred for student teachers themselves during their first impressions towards the lab and the ICT tools, as mentioned. Consequently, the context that ICT tools are framed by users is not always compatible with their educational purpose and therefore, that delimits their educational value or raises the difficulty for using them in the educational context.

Concerns about shortage of tools in schools or the high economical value of ICT tools were also stated by student teachers. In particular, 3 student teachers explicitly expressed concerns whether these tools or practices with these tools in the university could be transferred to schools due to their high cost and availability issues. We could hypothesise that these student teachers regarded the integration of ICT in schools as a rather unrealistic goal and hence that may have delimited their engagement in integrating ICT, a statement that needs further research.

Finally, a considerable amount of student teachers (n = 6) expressed some characteristic notions about the ICT tools in relation to their content-specific goals, as stated below.

> 1b: shortage of lab instruments for further implementation and modification of experiments.
> R: what does that mean?
> 1a: I mean that.
> 1b: that we wanted to, let's say I had seen an experiment from another group and we wanted to evolve that more, but we couldn't find any other instrument that we hadn't used before. Let's say in Chemistry we have only the pHmeter, we didn't have anything else to log data. That we didn't have many.
> 1a: tools to use.
> 1b: tools in each branch of science. I mean even in Thermodynamics there was only the [digital] thermometer, nothing else. Like in Chemistry there was only the pHmeter, there was nothing else to log data there.

As shown from the above reflections, student teachers often tended to connect the use of a datalogging sensor with a characteristic experiment, which, in cases that it was previously been implemented, its use became subsequently saturated. On the contrary, they didn't regard a datalogging tool/sensor as a tool that could be used for datalogging of a physical magnitude that could be used for a wide variety of experiments. This view not only denotes lack of TCK, but also reveals rather instrumental views of ICT tools, i.e. emphasising technological tools as mere devices whilst marginalising human contributions and use about their design and operation, as stressed from researchers of nature of technology (DiGironimo, 2011; Waight & Abd-El-Khalick, 2012).

## 4.5 Discussion

The present study investigates primary student teachers' integration of datalogging in designing science laboratory teaching material, as well as the factors that affect or impede the integration of ICT. Overall, student teachers managed to make good use of datalogging systems for the design of science experiments in the majority of cases. However, outputs of the study denote difficulties on integrating datalogging systems in a considerable amount of cases. Moreover, in a non-negligible number of experiments, ICT was integrated in a procedural way, without adding an additional value to the design of the experiment, which could be characterised as 'passive' use.

Students' reflections in the discussions that took place in the LC meetings reveal several deficiencies related to integrating ICT. First, lack of knowledge, TCK and CK in specific, impeded integration of technology, since they added additional layers of complexity and subsequently impeded the cultivation of TPACK. Noteworthily, TCK knowledge seemed to be highly context-specific, since general knowledge about educational technology did not result to acquaintance with using datalogging for designing ICT-rich science experiments.

Second, student teachers' previous lab experiences as students or as practitioners with simple non-digital instructional materials, as stated in their reflections, seemed to have shaped representations the safety to which student teachers returned to in cases they reached a dead-end with integrating ICT. The above issue in combination with student teachers' orientation in prioritising PCK issues when designing teaching material, indicate a PCK to TPACK approach. However, in this approach, teachers' previous experiences and beliefs often limit their vision to incorporate ICT (Niess et al., 2010). Hence, it would be worthwhile in technology integration programmes to orientate teachers to develop a PCK and TPACK simultaneously model (Koehler et al., 2014) e.g. in cases when they deal with open interdisciplinary topics, in out of the usual curriculum topics, since this way teachers are given the chance to develop both innovative PCK and TPACK.

Third, student teachers often held limited views on technology that indisputably affected their implementation and use in the experiments. Particularly, they mostly regarded dataloggers as devices exclusively for measuring data and not as an inquiry tool appropriate in assisting students to express and compare their misconceptions on empirical phenomena. Furthermore, they tended to relate a device/sensor with a specific experiment and not as measuring a physical magnitude useful in a variety of experiments. The above rather reflect students' limited views on technology as mere objects/artefacts, marginalising knowledge and human practice contributions (DiGironimo, 2011; Waight & Abd-El-Khalick, 2012). Student teachers also held rather outdated views about students' familiarity and comprehension on ICT. They tended to interpret technology according to their own era as digital 'immigrants' by neglecting the contemporary technological environment kids were born and raised as digital 'natives' (Prensky, 2001). Views also on limited availability in schools and high cost of the devices rather formulated unrealistic views on what they were doing compared to actual school practice, which potentially influenced negatively their attitudes towards ICT. Additionally, student teachers initially held views on ICT for non-educational purposes e.g. entertainment, and so did they mentioned that they noticed about their students, which results on disengagement and limited interest on using ICT for task-related purposes.

Fourth, some critical cultural incompatibilities shouldn't be overlooked when integrating ICT. In specific, the cultivation of practical technological skills usually requests personal-driven engagement with open-ended problems, whilst often users address failures, malfunction and damage, measurement errors and inaccuracies. Hence, users tend to get acquainted with technology under a rather pragmatic and student-centered approach. On the contrary, student teachers felt insecurity in dealing with technical issues, whilst they rather preferred a more traditional training approach concerning ICT, in which a priori extended training and confirmatory support would be provided. This cultural incompatibility that student teachers addressed was regarded as an important obstacle for integrating ICT.

Finally, it is imperative to interpret the success of technology integration by investigating not only teachers but also the ICT tools themselves, i.e. their features and use in a more holistic and ecological perspective. In particular, the portability feature was not implemented meaningfully in the experiments as it didn't gain high status and priority under teachers' point of view. Although we may consider that this feature prerequisites increased TCK in order to be implemented, we also consider reasonable that a feature like this did not seem particularly useful for teachers in a static indoor lab setting e.g. working in the limited space of a lab work bench full of sockets. In other words, this ICT feature did not gain high applicability for student teachers in the ecological environment of a science laboratory. Further research on using portable devices in other indoor and outdoor contexts could shed more light towards the usability of this feature.

Overall, integrating ICT was considered a complex task that is sensitively dependent not only from previous TPACK knowledge, but also views and attitudes on technology, previous experiences and conceptualisations on the role of ICT for learning. Concluding, we could interpret the previous factors as *personal amplifiers and filters* that can highly influence the formulation of TPACK, in a similar way that they affect the formulation of PCK, whilst interacting also with topic-specific professional knowledge and student outcomes (Gess-Newsome, 2015).

Consequently, integrating ICT could well be characterised both as teacher-, tools- and context-specific and therefore, teacher training programmes should consider more holistic and ecological perspectives in order to achieve efficacy in educating future generations of technological literate teachers.

## References

Barton, R. (2005). Supporting teachers in making innovative changes in the use of computer-aided practical work to support concept development in physics education. *International Journal of Science Education, 27*(3), 345–365. https://doi.org/10.1080/0950069042000230794

Bell, R. L., Maeng, J. L., & Binns, I. C. (2013). Learning in context: Technology integration in a teacher preparation program informed by situated learning theory. *Journal of Research in Science Teaching, 50*(3), 348–379. https://doi.org/10.1002/tea.21075

Bisdikian, G., & Psillos, D. (2002). Enhancing the linking of theoretical knowledge to physical phenomena by real-time graphing. In Psillos, D., & Niedderer, H., (Eds.), *Teaching and learning in the science laboratory* (pp. 193–204). Springer. https://doi.org/10.1007/0-306-48196-0_21

Chen, S., Chang, W. H., Lai, C. H., & Tsai, C. Y. (2014). A comparison of students' approaches to inquiry, conceptual learning, and attitudes in simulation-based and microcomputer-based laboratories. *Science Education, 98*(5), 905–935. https://doi.org/10.1002/sce.21126

Couso, D. (2016). Participatory Approaches to Curriculum Design From a Design Research Perspective. In *Iterative Design of Teaching-Learning Sequences* (pp. 47–71). Springer. https://doi.org/10.1007/978-94-007-7808-5_4

Dawson, V. (2008). Use of information communication technology by early career science teach-ers in Western Australia. *International Journal of Science Education, 30*(2), 203-219. https://doi.org/10.1080/09500690601175551.
DiGironimo, N. (2011). What is technology? Investigating student conceptions about the nature of technology. *International Journal of Science Education, 33*(10), 1337–1352. https://doi.org/10.1080/09500693.2010.495400
Donnelly-Hermosillo, D. F., Gerard, L. F., & Linn, M. C. (2020). Impact of graph technologies in K-12 science and mathematics education. *Computers & Education*, *146*, 103748.
Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The model of educational reconstruction—A framework for improving teaching and learning science. In *Science education research and practice in Europe* (pp. 13–37). SensePublishers, Rotterdam. https://doi.org/10.1007/978-94-6091-900-8_2
Ertmer, P. A., & Ottenbreit-Leftwich, A. (2013). Removing obstacles to the pedagogical changes required by Jonassen's vision of authentic technology-enabled learning. *Computers & Education, 64*, 175–182. https://doi.org/10.1016/j.compedu.2012.10.008
Farjon, D., Smits, A., & Voogt, J. (2019). Technology integration of pre-service teachers explained by attitudes and beliefs, competency, access, and experience. *Computers & Education, 130*, 81–93. https://doi.org/10.1016/j.compedu.2018.11.010
Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. *Re-Examining Pedagogical Content Knowledge in Science Education, 41*(7), 28–42. https://doi.org/10.4324/9781315735665-8
Hofstein, A., Kipnis, M., & Abrahams, I. (2013). How to learn in and from the chemistry laboratory. In Eilks, I., & Hofstein, A. (Eds.), *Teaching chemistry—A studybook* (pp. 153–182). Brill Sense. https://doi.org/10.1007/978-94-6209-140-5_6
Ifinedo, E., Rikala, J., & Hämäläinen, T. (2020). Factors affecting Nigerian teacher educators' technology integration: Considering characteristics, knowledge constructs, ICT practices and beliefs. *Computers & Education*, *146*, 103760. https://doi.org/10.1016/j.compedu.2019.103760
Iliaki, G., Velentzas, A., Michailidi, E., & Stavrou, D. (2019). Exploring the music: A teaching-learning sequence about sound in authentic settings. *Research in Science & Technological Education, 37*(2), 218–238. https://doi.org/10.1080/02635143.2018.1526170
Juuti, K., Lavonen, J., & Meisalo, V. (2016). Pragmatic Design-based research—Designing as a shared activity of teachers and researches. In Psillos, D., & Kariotoglou, P. (Eds.), *Iterative design of teaching-learning sequences* (pp. 35–46). Springer. https://doi.org/10.1007/978-94-007-7808-5_3
Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education, 193*(3), 13–19. https://doi.org/10.1177/002205741319300303
Koehler, M. J., Mishra, P., Kereluik, K., Shin, T. S., & Graham, C. R. (2014). The technological pedagogical content knowledge framework. In *Handbook of research on educational communications and technology* (pp. 101–111). Springer. https://doi.org/10.1007/978-1-4614-3185-5_9
Lavonen, J., Juuti, K., & Meisalo, V. (2003). Designing a user-friendly microcomputer-based laboratory package through the factor analysis of teacher evaluations. *International Journal of Science Education, 25*(12), 1471–1487. https://doi.org/10.1080/0950069032000072755
Liu, C. Y., Wu, C. J., Wong, W. K., Lien, Y. W., & Chao, T. K. (2017). Scientific modeling with mobile devices in high school physics labs. *Computers & Education*, *105*, 44–56. https://doi.org/10.1177/002205741319300303
Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education, 103*(4), 799–822. https://doi.org/10.1002/sce.21522
Mayring, P. (2015). Qualitative Content Analysis: Theoretical Background and Procedures. In Bikner-Ahsbahs, A., Knipping, C., Presmeg, N. (Eds.), *Approaches to qualitative research in mathematics education*, (pp. 365–380). Springer. https://doi.org/10.1007/978-94-017-9181-6_13

Mishra, P. (2019). Considering contextual knowledge: The TPACK diagram gets an upgrade. *Journal of Digital Learning in Teacher Education, 35*(2), 76–78. https://doi.org/10.1080/21532974.2019.1588611

Niess, M. L., van Zee, E. H., & Gillow-Wiles, H. (2010). Knowledge growth in teaching mathematics/science with spreadsheets: Moving PCK to TPACK through online professional development. *Journal of Digital Learning in Teacher Education, 27*(2), 42–52. https://doi.org/10.1080/21532974.2010.10784657

Nicolaou, C. T., Nicolaidou, I., Zacharia, Z., & Constantinou, C. P. (2007). Enhancing fourth graders' ability to interpret graphical representations through the use of microcomputer-based labs implemented within an inquiry-based activity sequence. *Journal of Computers in Mathematics and Science Teaching, 26*(1), 75–99. https://doi.org/10.1002/tea.3660240408

Nipyrakis, A. & Stavrou, D. (2019). Collaborating primary student teachers in designing experiments with the use of ICT. In *ESERA Conference, Bologna*, August 26–30, 2019.

National Research Council. (1996). *National science education standards*. National Academies Press. https://doi.org/10.17226/4962

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. https://doi.org/10.17226/13165

Odom, A. L., Marszalek, J. M., Stoddard, E. R., & Wrobel, J. M. (2011). Computers and traditional teaching practices: Factors influencing middle level students' science achievement and attitudes about science. *International Journal of Science Education, 33*(17), 2351–2374. https://doi.org/10.1080/09500693.2010.543437

Papanastasiou, E. C., Zembylas, M., & Vrasidas, C. (2003). Can computer use hurt science achievement? The USA results from PISA. *Journal of Science Education and Technology, 12*(3), 325–332. https://doi.org/10.1023/a:1025093225753

Prensky, M. (2001). Digital natives, digital immigrants part 2: do they really think differently? *On the Horizon, 9*(6), 1–6. https://doi.org/10.1108/10748120110424843

Prestridge, S. (2017). Examining the shaping of teachers' pedagogical orientation for the use of technology. *Technology, Pedagogy and Education*, 1–15. https://doi.org/10.1080/1475939X.2016.1258369

Sokoloff, D. R., Laws, P. W., & Thornton, R. K. (2007). Real time physics: Active learning labs transforming the introductory laboratory. *European Journal of Physics, 28*(3), S83. https://doi.org/10.1088/0143-0807/28/3/s08

Sokoloff, D. R. (2017). Enhancing learning in lab and lecture with real time physics labs (RTP) and interactive lecture demonstrations (ILDs) using computer-based data acquisition tools, personal response systems (clickers) and interactive video analysis. *Physics Teachers' Inventions Fair*, 3–4.

Tortosa, M. (2012). The use of microcomputer based laboratories in chemistry secondary education: Present state of the art and ideas for research-based practice. *Chemistry Education Research and Practice, 13*(3), 161–171. https://doi.org/10.1039/c2rp00019a

Van Dijk, E. M., & Kattmann, U. (2007). A research model for the study of science teachers' PCK and improving teacher education. *Teaching and Teacher Education, 23*(6), 885–897. https://doi.org/10.1016/j.tate.2006.05.002

Waight, N., & Abd-El-Khalick, F. (2007). The impact of technology on the enactment of "inquiry" in a technology enthusiast's sixth grade science classroom. *Journal of Research in Science Teaching, 44*(1), 154–182. https://doi.org/10.1002/tea.20158

Waight, N., & Abd-El-Khalick, F. (2012). Nature of technology: Implications for design, development, and enactment of technological tools in school science classrooms. *International Journal of Science Education, 34*(18), 2875–2905. https://doi.org/10.1080/09500693.2012.698763

Waight, N., & Abd-El-Khalick, F. (2018). Technology, culture, and values: implications for enactment of technological tools in precollege science classrooms. In *Cognition, Metacognition, and Culture in STEM Education* (pp. 139–165). Springer. https://doi.org/10.1007/978-3-319-66659-4_7

Waight, N., & Neumann, K. (2020). 21st-century science education digital ecologies: Technology, technique, shoelaces, promise, and pitfalls? *Journal of Research in Science Teaching, 57* (9). [Editorial]. https://doi.org/10.1002/tea.21667

Warr, M., Mishra, P., & Scragg, B. (2019). Beyond TPACK: Expanding technology and teacher education to systems and culture. *In Society for Information Technology & Teacher Education International Conference* (pp. 2558–2562). Association for the Advancement of Computing in Education (AACE), Las Vegas, March 18–22, 2019.

Wong, M., Quast, G., & Braig, D. (2020). Implementing a Raspberry Pi based digital measurement system in undergraduate physics education. *European Journal of Physics Education*, *11*(3), 1–16. https://doi.org/10.20308/ejpe.v11i3.297

Wong, W. K., Chen, K. P., & Chang, H. M. (2020). A comparison of a virtual lab and a microcomputer-based lab for scientific modelling by college students. *Journal of Baltic Science Education*, *19*(1), 157–173. https://doi.org/10.33225/jbse/20.19.157

Ye, J., Lu, S., & Bi, H. (2019). The effects of microcomputer-based laboratories on students macro, micro, and symbolic representations when learning about net ionic reactions. *Chemistry Education Research and Practice, 20*(1), 288–301. https://doi.org/10.1039/C8RP00165K

Zucker, A. A., Tinker, R., Staudt, C., Mansfield, A., & Metcalf, S. (2008). Learning science in grades 3–8 using probeware and computers: findings from the TEEMSS II project. *Journal of Science Education and Technology*, *17*(1), 42–48. https://doi.org/10.33225/jbse/20.19.157

# Chapter 5
# Engaging Pre-service Teachers and Children in STEM Through Educational Simulations

**Aslı Saylan Kırmızıgül and Esra Kızılay**

**Abstract** The aim of this research is to investigate the preschool and primary school pre-service teachers', and preschool and primary school students' views on Algodoo-based STEM applications. In this context, six-week training was given to the pre-service teachers. They prepared lesson plans and designed simulations, and taught lesson to the students. The research was carried out in the fall semester of 2020–2021 academic year. The data was obtained from 120 senior pre-service teachers from four universities and 50 students from 12 schools in Turkey. Within the scope of the study, semi-structured interviews were carried with the pre-service teachers and students. Content analysis conducted for the qualitative data obtained. According to the findings, the pre-service teachers mostly designed their simulations on physics subjects. Both pre-service teachers and students stated that Algodoo simulation-based STEM applications increased their STEM and science knowledge, motivation towards science teaching/learning. The participants found activities fun and enjoyable.

**Keywords** Algodoo · Simulation · STEM · Pre-service teachers · Preschool · Primary school

## 5.1 Introduction

Studies in the field of neuroscience show that the experiences in the first years of life are very critical in shaping the cerebral architecture of children (Sripada, 2012). The studies in the field of education also revealed that information obtained at an early age on science, technology, engineering and mathematics significantly contribute to children's future level of success, knowledge and skills (Morgan et al., 2016; Watts et al., 2014). Individuals are born with an intrinsic curiosity towards the world, and tend to investigate and discover what is going on around them, particularly at early ages (Helm & Katz, 2016; Ministry of National Education (MoNE),

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2013; National Research Council (NRC], 2012). Children like constructing, gathering objects, arranging collections, breaking them to pieces and reconstructing them. Therefore, STEM education is very suitable for this age group (Sarama et al. 2018). Within this framework, the National Science Teachers Association (NSTA) (2014) stated that learning science and engineering applications in the early years of education will reinforce children's curiosity towards exploring the world around them, and form the basis for all scientific studies they will receive throughout their lives.

According to Piaget's theory of cognitive development, children can think logically about concrete events but cannot think the abstract ones until the age of 11. Considering this situation, the share of teaching technologies in concretization of these events is undeniable. STEM approach plays a very important role in raising scientifically and technologically literate individuals with twenty-first century skills, and offers students different learning experiences by bringing together science, technology, engineering and mathematics. As STEM education becomes increasingly important, so does the importance of preparing teachers who are equipped to implement STEM education in their classrooms (Akaygun & Aslan-Tutak, 2020). In order to make STEM education more effective and efficient, using educational technologies like interactive learning environments, digital games, augmented reality, simulations and robots is at the top of the agenda of researchers (Wu & Anderson, 2015).

STEM studies in the literature are mostly focused on pre-service science teachers (Alan et al., 2019; Buber & Unal Coban, 2020; Ong et al., 2020) and middle-school students (Canbazoğlu Bilici et al., 2021; Guffey et al., 2020; Wieselmann et al., 2020). On the other hand, preschool is the education level where the least number of STEM studies are conducted (Akgündüz & Akpınar, 2018; Martín Páez et al., 2019; Ültay & Aktaş, 2020). Chesloff (2013) suggested that STEM education should start from the preschool period. Studies show that preschool teachers rarely receive in-depth professional preparation in math and science, resulting in insufficient STEM content knowledge and lack of confidence in their own abilities to implement high quality STEM learning experiences for children (Brenneman et al., 2019). Similarly, many primary school teachers have limited specialized knowledge in STEM areas and often lack confidence in teaching some of the content they are expected to teach (Danaia, & Murphy, 2020). Therefore, it is important to make creative STEM activity suggestions for preschool and primary school pre-service teachers to carry out in their classes. This research was planned for this need. In this research, through the training, it was aimed to enhance pre-service teachers' pedagogical content knowledge and STEM knowledge together. After the training, in the implementation process, while designing the simulations they also integrate their pedagogical content knowledge and science, technology, engineering and mathematics knowledge. In this regard, the study is envisaged as a STEM application.

Rapid technological developments have made information and communications technologies a trend in education (Vidakis et al., 2019). New educational technologies that are claimed to be effective/potentially effective in eliminating existing problems and increasing the quality of education are emerging. Educational environments that will integrate new technologies into education and test their efficiency in terms of increasing the quality of education are needed. Within this framework, devices or interfaces allowing users to interact with digital information by manipulating physical objects or materials have been quite popular in recent years (Ishii, 2008). One of the said technological applications is Algodoo. Starting from this point, within the framework of this research, training about simulation-based learning, and more specifically, using Algodoo software was given to the primary school and preschool pre-service teachers. Then the pre-service teachers prepared lesson plans and designed Algodoo-based STEM applications for students. By this way, primary and preschool students also learned the Algodoo software and experience Algodoo-based STEM courses. Lastly, the pre-service teachers' and students' views on their experiences regarding the simulation-based STEM applications were investigated. Therefore, this research can lead to a snowball effect and generate cumulative change.

Specifically, the following research questions were asked in the research:

(1) What are the primary school and preschool pre-service teachers' views on Algodoo simulation-based STEM education?
(2) What are the primary school and preschool students' views on Algodoo simulation-based STEM education?

## 5.2 Background

### *5.2.1 Simulation-Based Learning*

Simulation is described as software that simulates natural phenomena realistically and in safe conditions. Simulations help individuals understand, record and analyze different phenomena related to the natural sciences, repeat the experiment and solve problems they may encounter (Poultsakis et al., 2021).

Simulation-based learning is a constructivist learning model that provides a simplified and simulated world or system experience of working. It provides individuals with a deeper and more memorable experience by enabling them to use psychomotor, affective and cognitive learning areas (Brookfield, 2015). Simulation-based learning takes its foundation from Kolb's experiential learning theory. According to Kolb (1984), learning is not an outcome, but a process in which an individual reaches knowledge through his/her experiences (p. 27). The experiential learning theory is based on the learning cycle model that includes four stages in which students act in the learning process. Zigmont et al. (2011) discussed simulation-based learning on the basis of Kolb's (1984) Experiental Learning Cycle as follows:

(1) Concrete experience: With concrete experiences, students can identify their own knowledge gaps.
(2) Reflective observation: Students identify gaps in their mental models and prepare for learning.
(3) Abstract conceptualization: Students are enabled to bridge the gap between what they have learned during the simulation experience and their future experiences.

(4) Active experimentation: Students try out new ideas immediately. This active experimentation enables the reinforcement of new knowledge and consolidation of the new mental models.

In simulation-based learning, firstly a problem is put forward in. Then, students are asked to make predictions for the solution of this problem. Based on this prediction(s), a simulation (model) is created for the solution of the problem. Then, the created model is tested and data is collected. Finally, an evaluation is made (Koparan & Kaleli Yilmaz, 2015).

STEM education is very suitable for simulation-based learning in terms of content (Landriscina, 2017; Urban & Falvo, 2016). Moreover, computer simulations are very effective in learning difficult concepts, especially in STEM disciplines (D'Angelo et al., 2013; Lindgren et al., 2016). Adapting simulations to teach science in preschool and primary education depends on whether the teachers themselves believe that simulations contribute positively to their teaching methods. From this point of view, this research aims to investigate the perceptions of pre-service teachers in adopting simulation-based STEM activities in teaching science.

Due to COVID-19 pandemic, distance education has gained importance to provide the continuum of the learning. However, distance education may decrease success for courses such as science where experimental applications are important. At this point, the importance of simulation-based software programs such as PhET, Crocodile Physics, Interactive Physics and Algodoo is increasing day by day. Simulations make understanding costly, time-consuming and dangerous experiments to be performed in the laboratory/ classroom, events that cannot be observed in real life, and complex concepts that are difficult to think in three dimensions (Trey & Khan, 2008). Thus, students will do experiments that they cannot do with real materials in home environment using these applications, so they will not fall behind in the class.

### *5.2.2 Algodoo*

Algodoo is a 2D educational software. Using this digital learning environment, users can create interactive experiments in a short time without writing a code and learn interactively by testing their hypotheses on a computer, smartboard or tablet. Algodoo software allows simulation scenes to be created by using simple drawing tools such as box, circle, gear, rope, chain and by changing different parameters such as density, mass, color, size, velocity, gravity, friction and refractive index. The user also gets a graph of the motion over time while running the simulation. Thus, students apply the formulas and laws concretely instead of memorizing them and to connect real-life phenomena to the science. Algodoo also makes it possible to save and share the created simulations. On the Algodoo forum; educators, parents and students who are using this program all over the world can discuss interesting topics, express their opinions about the program, and use the simulations and lesson plans created by each other, either exactly the same as the originals or by modifying them.

In this research, Algodoo was preferred for reasons such as being free and flexible in terms of usage, enabling students to develop their creativity by making their own designs, and providing suitable activities for STEM approach. Algodoo coincides with the structure of STEM in that it provides an environment where students are active, use their science, mathematics and technology knowledge and engineering skills, and develop their creativity by making their own designs. It is known that Algodoo promote students' and children's self-determination, meaningful learning and problem-solving skills and increase student engagement (Alan et al., 2019). Algodoo also increase science achievement (Cayvaz & Akcay, 2018; Saylan Kirmizigul, 2019), motivation (Saylan Kirmizigul, 2019; Tastan Akdag, & Gunes, 2018; Tembo & Lee, 2017) and attitude towards science (Saylan Kirmizigul, 2019), and creativity (Tastan Akdag & Gunes, 2018). Although these advantages, no research has been reached conducting Algodoo on preschool or primary school students yet.

## 5.3 Method

### *5.3.1 Research Design*

A qualitative research study was conducted to identify pre-service teachers' and children's views about STEM applications. Qualitative research is useful for describing the perspectives of a participant group toward events, beliefs or practices (Gay & Airasian, 2000). In qualitative research, the researcher does not aim to make generalizations about the subject that s/he investigate. In this research paradigm, the researcher aims to collect detailed data on the participants.

### *5.3.2 Participants*

In this study, participants were selected using criterion sampling, which is one of the purposive sampling methods. The purposive sampling method is a sampling method that primarily used in qualitative studies and leads to greater depth of information (Patton, 2002). In the study, predetermined criterion is that the participants must took and passed 'Teaching Practice I', 'Computer I', 'Computer II', and 'Instructional Technologies and Material Design' courses. Within this context, the participants of the study are 120 senior pre-service teachers (55 preschool pre-service teachers-40 female, 15 male; 65 primary school pre-service teachers-41 female, 24 male) from four universities.

After the training was completed, pre-service teachers gave lectures to 320 students (ages 6 to 10; 162 girls, 158 boys) from 12 different schools within the framework of the lesson plan they prepared.

### 5.3.3 Ethical Principles

The aim of this research is to investigate the preschool and primary school pre-service teachers', and preschool and primary school students' views on Algodoo-based STEM applications. In this context, six-week training was given to the pre-service teachers. In the ethical framework, it is important for pre-service teachers to be informed about the research process and to participate voluntarily in research. Before the research, the pre-service teachers were informed about the process and the research was started on a voluntary basis. In the research, the data was clearly coded to prevent research misconduct. The real names of individuals were not used to reduce individual harm (Petousi & Sifaki, 2020).

### 5.3.4 Training and Implementation

The training and implementation processes were carried out online through live online classes via the Zoom platform. The data comes from six weeks (three hours in a week) of classroom activities in the fall semester of 2020–2021 academic year (see Table 5.1).

In the first week, the researchers from a Turkish research-intensive university taught STEM, simulation-based learning, and to use Algodoo software in STEM education. Sample simulation-based activities on biology, chemistry and physics concepts were conducted with the participation of pre-service teachers. The researchers gave equal attention to all subject areas during the training process.

In the second week, the pre-service teachers were asked to prepare lesson plans including STEM learning objectives and the learning objectives in the curriculum. The lesson plans were mostly prepared in accordance with the 5E and 7E learning models, and engineering design process. The pre-service teachers worked in groups

**Table 5.1** Topics and contents of the 6-week implementation process

| Week | Topic | Content |
|---|---|---|
| 1 | • What is the future learning and teaching should be? | • Twenty-first century skills |
| | • Why STEM is important? | • STEM definition, STEM literacy |
| | • Teaching STEM with Algodoo | • Using Algodoo in STEM |
| 2 | • STEM lesson plan development | • STEM learning objectives |
| | • STEM lesson plan presentation and feedback | • Learning objectives in the curriculum |
| 3–4 | • Designing the Algodoo simulations | • Learning objectives and indicators |
| | • Discussing the challenges | • The Next Generation Science Standarts |
| 5–6 | • STEM lesson plan implementation | • Conducting simulations with children |

of two or three. In total, 50 groups (23 preschool pre-service teacher groups, 27 primary school pre-service teacher groups) were created. Each group prepared one lesson plan based on the learning objectives and topics in the fall semester of the curriculum. One of the researchers and one STEM education expert evaluated the lesson plans using the rubric and gave feedbacks to the pre-service teachers. Then the pre-service teachers revised their plans.

In the next 2 weeks, the pre-service teachers designed STEM simulations based on their lesson plans. Preschool pre-service teachers designed their simulations based on the learning objectives and indicators included in the preschool curriculum (Ministry of National Education [MoNE], 2013) and the Next Generation Science Standarts (NGSS, 2017, p. 5). Similarly, primary school pre-service teachers designed the simulations based on learning objectives in the science curriculum (MoNE, 2018) and the NGSS (2017, p.9). The researcher visited each group to work with them as needed both on their simulation and their pedagogical focus. They were encouraged to share reflections on their experiences of the simulations and to discuss with classmates the challenges that would emerge in their interactions. Lastly, they redesigned their simulations to address the challenges they experienced initially.

After the 4-week training process, in the last two weeks, the pre-service teachers in each group taught lessons through simulation-based learning within the framework of school experience course. The lessons were carried out online through the Zoom platform. Before the lessons, it was ensured that each student downloaded the Algodoo software to their computer. The pre-service teachers conducted simulations regarding the topic they taught and shared them with children through Zoom (see Figs. 5.1,5.2, 5.3, 5.4, 5.5 and 5.6). Since each student has his or her own computer, the simulation-based activities were carried out under the guidance of the teacher with the active participation of children. The students conducted STEM activities,

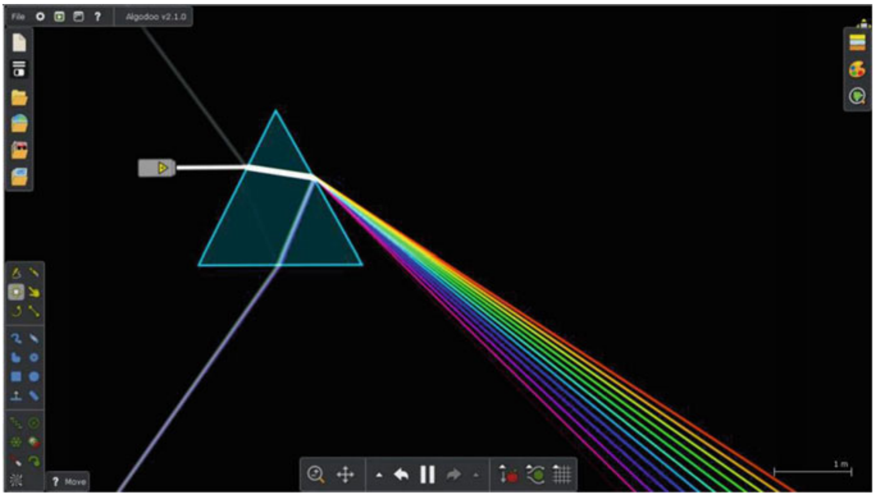

**Fig. 5.1** Newton's prism experiment for primary school students in Algodoo

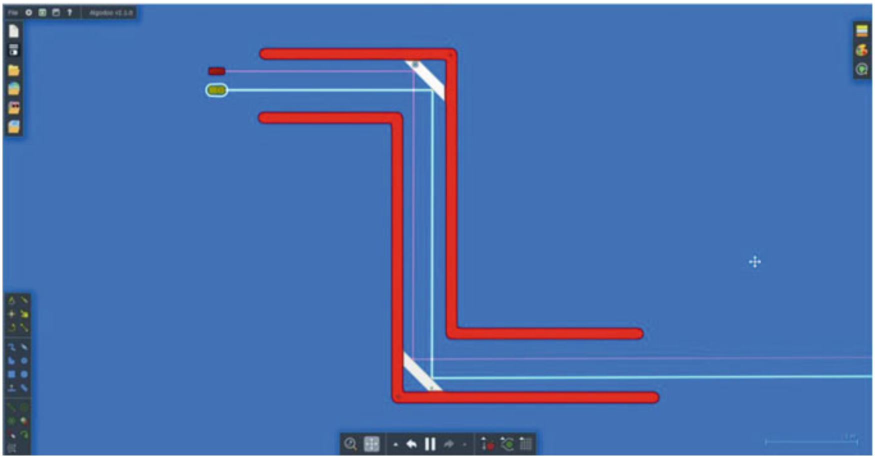

**Fig. 5.2** "Making a periscope" for primary school students in Algodoo

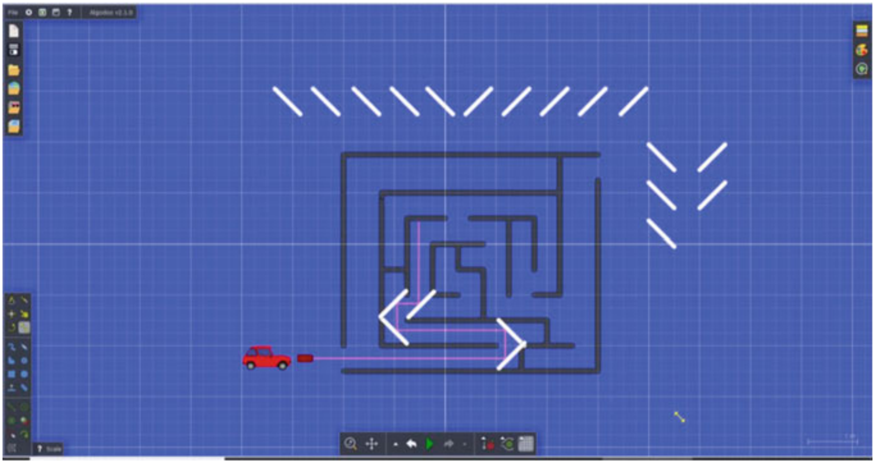

**Fig. 5.3** "Escaping the labyrinth" game for primary school students in Algodoo

designed their own simulations and shared them with the classroom by screen sharing. Each course was observed by one of the researchers and one teacher.

### 5.3.5 *Data Collection*

After the implementation process is completed, four forms of data were collected:

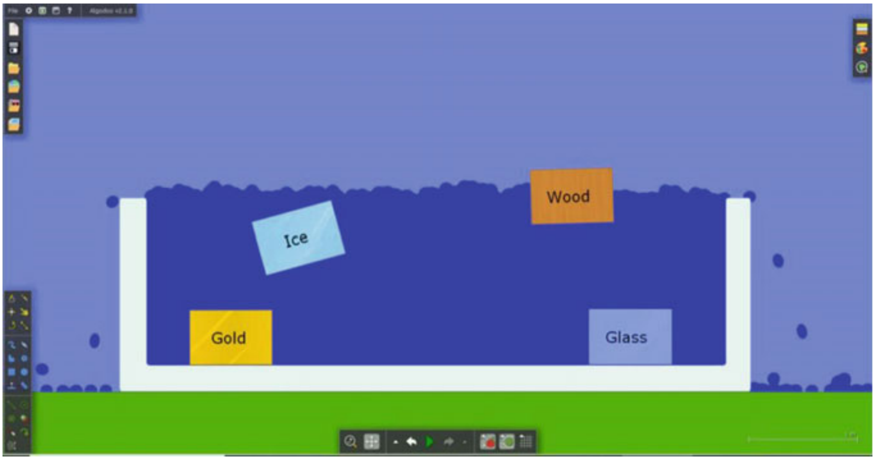


**Fig. 5.4** "Sink or float" experiment for preschool students in Algodoo

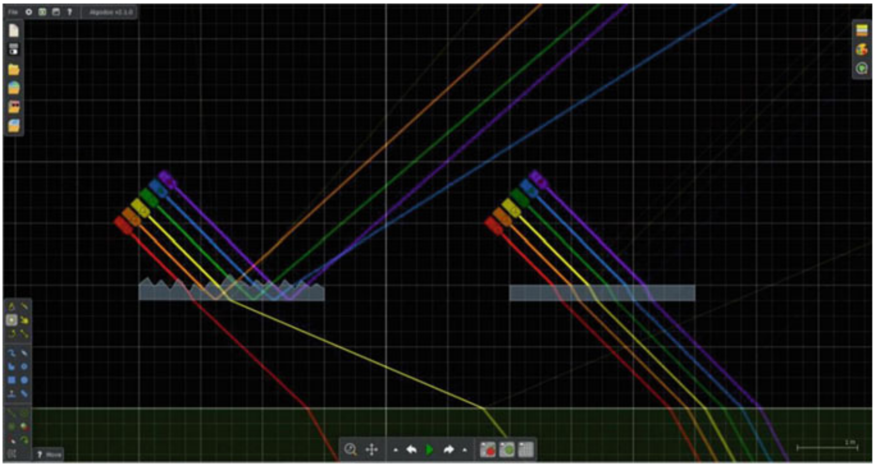

**Fig. 5.5** "Rough and smooth surfaces" experiment for preschool students in Algodoo

(1) The pre-service teachers' written memos on their experiences regarding the course,
(2) Lesson plans including the computer simulations prepared by the pre-service teachers,
(3) Video and audio recordings of interviews with the pre-service teachers,
(4) Video and audio recordings of interviews with the children (ages 6 to 10).

Data collection was carried out online. The written memos were collected from 120 pre-service teachers through the mail. The lesson plans including the computer simulations were collected from each of the 50 groups through the mail.

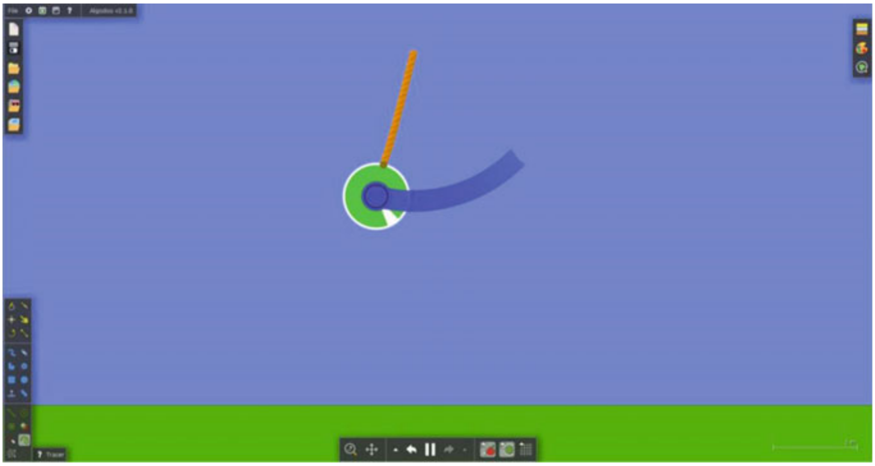

**Fig. 5.6** "Motion" experiment for preschool students in Algodoo

The semi-structured interviews were conducted using Zoom with 30 pre-service teachers (15 preschool pre-service teachers, 15 primary school pre-service teachers) and 50 children (25 preschool and 25 primary school students). In order to ensure the internal validity, expert opinion was received and the final form of the interview questions was given. Researchers recorded the interviews with the participants' permission via voice recorder in order to prevent possible data loss and to take precautions against the threats of internal validity.

Interview questions for pre-service teachers, and preschool and primary school students are as follow:

(1) What are the benefits of using Algodoo in STEM applications?
(2) What are the challenges of using Algodoo in STEM applications?

Each interview form was checked by two science education experts and the final versions were obtained. During the interviews, both the pre-service teachers and children were asked to explain the difficulties that they faced, and to describe their feelings and opinions about the simulations. The interviews were completed within a two-week time period.

### *5.3.6 Data Analysis*

In order to hide their names, pre-service teacher participants were coded as P1, P2, …, P30, and students were coded as S1, S2, …, S50. After the interviews were completed, the data obtained from the sound recordings were transcripted for analysis. The findings obtained in the study were shared with the participants and they were asked whether they agree with the analysis results or not. In order to enhance internal validity, direct quotations were included in the findings section. In order to ensure external validity, sample was selected appropriately for the purpose of study. Moreover, the research design, study group, data collection tool and process, analysis and findings were explained in detail.

The data about pre-service teachers' and students' views on simulation-based STEM education were analyzed using content analysis. Content analysis is used to formulate themes and categories in order to organize and make sense out of large amounts of descriptive information (Fraenkel et al., 2012). For written and verbal qualitative data, interpretive methods were used to explore common themes that emerged out of the pre-service teachers' statements and words. The two researchers made coding individually, and then reliability percentage was calculated based on Miles and Huberman's (1994) formula.

Inter-rater reliability was used to ensure the reliability of the interview form consisting of open-ended questions. The internal consistency coefficient of the instrument that was scored by two field experts was calculated as 0.92 (Miles & Huberman, 1994). Moreover, in order to enhance internal reliability of the study, the findings were presented without any interpretation, and the themes and codes were finalized after consultation with the two experts.

## 5.4 Findings

### *5.4.1 Lesson Plans Including the Computer Simulations Prepared by the Pre-service Teachers*

In total, 50 lesson plans were prepared by the pre-service teachers. The lesson plans including Algodoo simulations were rated out of 20 points using a rubric developed by the researchers. The rubric has five items:

(1) Ensuring the integration of science, technology, engineering and mathematics,
(2) Alignment with learning objectives in the curriculum,
(3) Alignment with the STEM learning objectives,
(4) Enabling students to develop twenty-first century skills,
(5) Ensuring the proper integration of Algodoo.

For each item, pre-service teachers were rated on a 4-point rubric. The participants were classified as exemplary (4-point), acceptable (3-point), developing (2-point), needs improvement (1-point) or unacceptable (0-point).

### 5.4.2 Lesson Plans Prepared by the Preschool Pre-service Teachers

According to the results, 23 lesson plans were prepared by the preschool pre-service teachers. 10 lesson plans had a high, eight of them had a moderate and five of them had a low score. 15 preschool pre-service teachers having different levels (six high, five moderate, four low-score) were selected for the interview process.

The results revealed that 5E and 7E learning models were followed in seven and 10 lesson plans, respectively. Engineering design process steps were followed in four lesson plans and problem-based learning model was applied in two lesson plans.

According to the results, preschool pre-service teachers generally designed physics simulations. They designed simulations on many different subjects such as motion, balance, crafts on land, water and air, states of matter, properties of matter (rough/smooth, flexible/ rigid, heavy/light, transparent/opaque etc.).

### 5.4.3 Lesson Plans Prepared by the Primary School Pre-service Teachers

According to the results, 27 lesson plans were prepared by the primary school pre-service teachers. 12 lesson plans had a high, nine of them had a moderate and six of them had a low score. 15 primary school pre-service teachers having different levels (six high, five moderate, four low-score) were selected for the interview process.

The results revealed that 5E and 7E learning models were followed in eight and 11 lesson plans, respectively. Engineering design process steps were followed in six lesson plans and problem-based learning model was applied in two lesson plans.

The primary school science curriculum has four subject areas: Earth and Universe, Living Things and Life, Physical Events, Matter and Its Nature (MoNE, 2018). According to the results, 19 (70.4%) of 27 primary school pre-service teacher groups designed simulations on Physical Events subject area. From these, 14 groups designed simulations on force concept, while five groups designed simulations on light concept. Eight groups (29.6%) designed simulations on Matter and Its Nature subject area, on the concepts of states and properties of matter. No lesson plan or simulation was prepared on Earth and Universe, and Living Things and Life subject areas.

### 5.4.4 Pre-service Teachers' Written Memos on Algodoo-based STEM Applications

According to the results obtained from the written memos, 110 pre-service teachers (91.7%) (62 primary school, 48 preschool) stated that Algodoo simulation-based

STEM applications provide many advantages such as developing twenty-first century skills, being fun, interesting and enjoyable, increasing STEM knowledge and motivation towards science teaching. On the other hand, 10 pre-service teachers (8.3%) (three primary school, seven preschool) stated that these activities have disadvantages such as being time consuming and having difficulty in learning the Algodoo software.

### 5.4.5 Pre-service Teachers' Views on Algodoo-based STEM Applications

In parallel with their written memos, pre-service teachers' statements regarding the advantages of the simulation-based STEM activities were grouped into four themes:

(1) Fun, interesting, enjoyable and exciting applications,
(2) Increased motivation to teach science,
(3) Developed twenty-first century skills (creativity, problem-solving, and critical thinking skills etc.),
(4) Increased knowledge.

The results obtained from the interviews revealed that all of the 30 pre-service teachers stated that Algodoo simulation-based STEM applications provide many advantages (see Table 5.2). The pre-service teachers generally stated that activities were fun (93.3%), enjoyable (86.7%), and they increased science and STEM knowledge (83.3%) and motivation to teach science (80.0%).

Five pre-service teachers (16.7%) noted three main challenges while carrying out the simulations:

(1) The lack of conceptual knowledge about STEM education (16.7%),
(2) Preparing the lesson plan and designing the simulation was time consuming (10.0%),
(3) Designing biology simulations is difficult (6.7%).

The results revealed that five pre-service teachers had difficulties since they have a lack of conceptual knowledge about STEM education. Three pre-service teachers stated that preparing the lesson plan and designing the simulation was time consuming. Lastly, only one pre-service teacher found designing biology simulations difficult.

### 5.4.6 Preschool Pre-service Teachers' Views on Algodoo-based STEM Applications

According to the results, 14 preschool pre-service teachers stated that Algodoo-based STEM applications provide many advantages. The analyses of the findings revealed

**Table 5.2** Pre-service teachers' opinions about Algodoo-based STEM applications

| Codes | Sample statements | Frequency | Percentage (%) |
|---|---|---|---|
| Fun | *"It was a fun activity that helped me improving myself. Algodoo applications are very enjoyable for both students and teachers."* (P2-preschool) | 28 | 93.3 |
| Enjoyable | | 26 | 86.7 |
| Increased knowledge | *"I learned how to design STEM simulations. I also learned how to integrate STEM learning objectives into the lesson."* (P13-preschool) | 25 | 83.3 |
| Increased motivation to teach science | *"Preparing lesson plans and designing simulations for students increased my motivation to teach science."* (P29-preschool) | 24 | 80.0 |
| Developed twenty-first century skills | *"Simulation-based STEM applications developed my creativity. I think these activities also develop students' twenty-first century skills such as creativity, problem-solving, critical thinking etc."* (P7-primary school) | 18 | 60.0 |
| Exciting | *"Designing simulations without writing codes is very interesting and exciting for me."* (P20-primary school) | 13 | 43.3 |
| Interesting | | 9 | 30.0 |

that 13 of them stated that activities were fun, enjoyable, and they increased STEM knowledge. 11 preschool pre-service teachers indicated that the activities increased their motivation to teach science.

The results revealed that four preschool pre-service teachers had difficulties since they have a lack of conceptual knowledge about STEM education. Moreover, a preschool pre-service teacher stated that preparing the lesson plan and designing the simulation was time consuming, and another one found designing biology simulations difficult.

### 5.4.7 Primary School Pre-service Teachers' Views on Algodoo-based STEM Applications

According to the results, 16 preschool pre-service teachers stated Algodoo-based STEM applications provide many advantages. 15 primary school pre-ser4.vice teachers stated that activities were fun, and 13 of them said that they are enjoyable and increased their motivation to teach science. 12 primary school pre-service teachers indicated that the activities increased their science and STEM knowledge.

The results revealed that one primary school pre-service teacher stated that s/he noticed s/he had a lack of conceptual knowledge about STEM education. In addition, two pre-service teachers stated that preparing the lesson plan and designing the simulation was time consuming.

### 5.4.8 Students' Views Regarding Algodoo-based STEM Applications

The results obtained from the interviews revealed that all of the 50 students stated that Algodoo-based STEM applications provide advantages (see Table 5.3). The students generally stated that activities were fun (64%), enjoyable (56%), and they increased

**Table 5.3** Students' opinions about Algodoo-based STEM applications

| Codes | Sample statements | Frequency | Percentage (%) |
|---|---|---|---|
| Fun | *"The lessons were very fun and enjoyable. It was like a game."* (S42-preschool) | 32 | 64.0 |
| Enjoyable | | 28 | 56.0 |
| Increased science conceptual knowledge | *"I learned about rough and smooth surfaces by experiencing."* (S38-preschool) | 32 | 64.0 |
| Increased motivation | *"It was very motivating to study, like playing a game. I started to love science."* (S8-primary school) | 26 | 52.0 |
| Exciting | *"Designing air craft on computer was very exciting for me."* (S13-primary school) | 19 | 38.0 |
| Interesting | *"I designed a lighting tool that can be used in the future. My friends found it really interesting and creative."* (S23-primary school) | 8 | 16.0 |

science conceptual knowledge (64%) and motivation to learn science (52%). On the other hand, two students stated that learning and using Algodoo is a bit difficult.

The students' statements regarding the advantages of simulation-based STEM activities were grouped into three themes:

(1) Fun, interesting, enjoyable and exciting applications,
(2) Increased motivation to learn science,
(3) Increased science conceptual knowledge.

### *5.4.9 Preschool Students' Views on Algodoo-based STEM Applications*

According to the results, 12 preschool students found the activities fun and enjoyable. 14 preschool students stated that these activities increased their science knowledge and 10 of them stated they increased their motivation to learn science. Lastly, six preschool found Algodoo-based STEM activities exciting and four students found interesting. On the other hand, two preschool students indicated that learning and using Algodoo simulation is difficult.

### *5.4.10 Primary School Students' Views on Algodoo-based STEM Applications*

The results obtained from the interviews revealed that 20 primary school students found the activities fun and 16 of them found them enjoyable. 18 primary school students stated that these activities increased their science knowledge and 16 of them stated they increased their motivation to learn science. 13 primary school students found Algodoo-based STEM activities exciting and four students found interesting. No primary school student found learning or using Algodoo simulation difficult.

## 5.5 Conclusion and Discussion

This research investigated the primary school and preschool pre-service teachers' and primary school and preschool students' views on Algodoo simulation-based STEM education. The study makes two main contributions. Firstly, we present a simulation software that almost all of the participants met for the first time, for integrating STEM in preschool and primary school pre-service teacher education. Secondly, we illustrate how simulations get reframed by pre-service teachers as pedagogical objects and experiences for doing and teaching science. The analysis presented here focuses on the pre-service teachers' experiences about both learning and teaching simulation-based STEM applications. Moreover, their students' experiences were also investigated.

The results revealed that pre-service teachers generally applied 7E learning model in their lesson plans. In support of this, while designing the STEM activity, following the steps of Excite, Explore, Explain, Elaborate, Extend, Exchange, and Evaluate in line with the 7E approach is suggested in the literature (Bybee, 2003). The combined use of STEM and 7E learning model helps students experience meaningful learning and facilitates the achievement of the targeted learning objectives specified in the curricula (Güven et al., 2018).

According to the results, most of the primary school pre-service teachers designed simulations on physics topics. Some of them designed simulations on chemistry concepts. However, no lesson plan or simulation was prepared on astronomy and biology concepts. When the studies done with Algodoo are examined, it is seen that biology was given a very little place in these studies (Gregorcic & Bodin, 2017; Tastan Akdag & Gunes, 2018). Although Algodoo is described as a "physics simulation" on its website, it is also very useful, especially for chemistry subjects. It is also possible to make some biology applications on it. Although the researchers paid attention to put equal emphasis on all subject areas during the training process, it is inevitable to obtain this finding when it is considered that 44.9% of the primary school science learning objectives are on the Physical Events. This rate is quite high and it makes sense that pre-service teachers have prepared lesson plans for physics learning objectives.

According to the results, both pre-service teachers and students found Algodoo activities fun, enjoyable, exciting and interesting. In parallel with this finding, in the study of Alan et al. (2019), pre-service science teachers found Algodoo applications enjoyable and fun. The pre-service teachers indicated that these STEM applications increased their motivation to teach science. Similarly, the students stated that Algodoo-based STEM activities increased their motivation to learn science. It is recommended that STEM applications at early ages should be based on tangible experiences and game-based learning (Allvin, 2020). In support of this, Algodoo was selected as the best application in STEM category by the American Association of School Librarians (AASL) (2015). Moreover, Euler and Gregorcic (2019) pointed out that Algodoo activities carry significant potential to motivate students and support their intrinsic interests. The findings also revealed that simulation-based STEM activities increased pre-service teachers' conceptual knowledge about STEM and students' science knowledge. In the literature, some other studies were also found that Algodoo activities increased science knowledge (Cayvaz & Akcay, 2018; Saylan Kirmizigul, 2019).

The findings revealed that two preschool students found learning and using Algodoo software difficult. Similarly, two primary school pre-service teachers and a preschool pre-service teacher found preparing lesson plan and designing simulation time consuming. Moreover, a preschool pre-service teacher stated that s/he had difficulty in designing Algodoo simulations. One of the reasons for this situation may be that the Algodoo software does not have a Turkish language option for now. However, its user interface is very practical. For this reason, although it may seem difficult to use at first, it is thought that these views will change as the participants use the software.

According to the results, one primary school and four preschool pre-service teachers stated that they had a lack of STEM conceptual knowledge. Concordantly, Karamustafaoğlu and Özmen (2004) argued that the most challenging thing for pre-service teachers while preparing lesson plan is the lack of content knowledge. The findings of many different study also show that preschool teachers do not know enough about STEM fields (Brenneman et al., 2019; Durland et al., 2009; Yıldırım, 2021). Danaia and Murphy (2020) indicated that both preschool and primary school teachers have insufficient STEM content knowledge and lack of confidence in implementing high quality STEM learning experiences for children.

## 5.6 Implications

Science education is a challenging process at all levels of education (Fokides & Papoutsi, 2020). With the research conducted, pre-service teachers did not only use Algodoo in STEM activities in active form, but also created a simulation pool which could be used in science education in the future studies.

The results revealed that some pre-service teachers found difficult to design simulations on biology concepts. Moreover, no lesson plan or simulation was prepared on astronomy and biology concepts. In order for this situation not to cause prejudice in teacher candidates that STEM education is not suitable for biology, it is suggested to focus on simulation-based STEM applications on biology concepts in the future studies. Considering the need in the literature, in the future studies, STEM activities can be carried out using different educational technologies for preschool and primary school students.

## 5.7 Limitations

Like all research, this research has some limitations that must be acknowledged. First of all, due to the pandemic conditions, K-12 learning was moved mostly and pre-service teacher education was moved fully online in Turkey. In parallel with this situation, in the study, both the training and implementation processes were carried out online through live online classes. Secondly, this study only represents the 120 preschool and primary school pre-service teachers and 320 preschool and primary school students, and therefore, an overgeneralization of the results should be avoided. We also were not able to interview all of the pre-service teachers or students. Lastly, the research was conducted in already-formed groups rather than in randomly chosen groups.

## References


Akaygun, S., & Aslan-Tutak, F. (2020). Collaboratively learning to teach STEM: A model for learning to integrate STEM education in pre-service teacher education. In *Critical questions in STEM education* (pp. 147–163). Springer.

Akgündüz, D., & Akpınar, B. C. (2018). Evaluation of STEM applications based on science education in preschool education in terms of students, teachers and parents. *Education for Life, 32*(1), 1–26.

Alan, B., Kırbag Zengin, F., & Kececi, G. (2019). Using STEM applications for supporting integrated teaching knowledge of pre-service science teachers. *Journal of Baltic Science Education, 18*(2), 158–170.

Allvin, R. (2020). Making connections: There's no such thing as online preschool. National Association for the Education of Young Children. https://www.naeyc.org/resources/pubs/yc/mar2020/theres-no-such-thing-online-preschool

American Association of School Librarians (AASL). (2015). AASL announces 2015 Best Apps for Teaching & Learning. https://www.ala.org/news/press-releases/2015/06/aasl-announces-2015-best-apps-teaching-learning

Brenneman, K., Lange, A., & Nayfeld, I. (2019). Integrating STEM into preschool education; designing a professional development model in diverse settings. *Early Childhood Education Journal, 47*(1), 15–28.

Brookfield, S. D. (2015). *The skillful teacher: On technique, trust, and responsiveness in the classroom*. John Wiley & Sons.

Buber, A., & Unal Coban, G. (2020). From modeling to STEM: A predictor activity of volcanic eruption. *Science Activities, 57*(3), 111–121.

Bybee, R. W. (2003). *Why The Seven E's*.

Canbazoğlu Bilici, S., Küpeli, M. A., & Guzey, S. (2021). Inspired by nature: An engineering design-based biomimicry activity. *Science Activities, 58*(2), 1–12.

Cayvaz, A., & Akcay, H. (2018). The effects of using Algodoo in science teaching at middle school. *The Eurasia Proceedings of Educational & Social Sciences, 9*, 151–156.

Chesloff, J. D. (2013). STEM education must start in early childhood. *Education Week, 32*, 32–27.

D'Angelo, C., Rutstein, D., Harris, C., Bernard, R., Borokhovski, E., & Haertel, G. (2013). *Simulations for STEM learning: Systematic review and meta-analysis executive summary.* SRI International.

Danaia, L., & Murphy, S. (2020). Pedagogical partnerships in primary and secondary STEM education. In *STEM Education Across the Learning Continuum* (pp. 249–267). Springer.

Durland, G., Karatas, F. O., & Bodner, G. M. (2009). *Pre-service teachers' beliefs about the relationship between basic chemistry concepts, the "real world", and their occupation* (pp. 85–89). ESERA.

Euler, E., & Gregorcic, B. (2019) Algodoo as a microworld: Informally linking mathematics and physics. In Pospiech, G., Michelini, M., Eylon, B. S. (Eds.), *Mathematics in Physics Education.* Springer.

Fokides, E., & Papoutsi, A. (2020). Using Makey-makey for teaching electricity to primary school students: A pilot study. *Education and Information Technologies, 25*, 1193–1215.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. (2012). *How to design and evaluate research in education.* McGraw Hill.

Gay, L. R., & Airasian, P. W. (2000). *Student guide to accompany educational research: Competencies for analysis and application.* Merill.

Gregorcic, B., & Bodin, M. (2017). Algodoo: A tool for encouraging creativity in physics teaching and learning. *The Physics Teacher, 55*(1), 25–28.

Guffey, S. K., Parrish, C. W., Ferguson, S. N., & Green, A. M. (2020). Successes and challenges of a summer STEM program for students from Title I schools. *Middle School Journal, 51*(3), 26–32.

Güven, Ç., Selvi, M., & Benzer, S. (2018). Teaching applications' based on 7E learning model centered STEM activity effect on academic achievement. *Journal of Social Sciences of Mus Alparslan University, 6*, 73–80.

Helm, J., & Katz, L. (2016). *Young investigators: The project approach in the early years*. Teachers College Press.

Ishii, H. (2008, February). Tangible bits: Beyond pixels. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (pp. xv-xxv).

Karamustafaoğlu, O., & Özmen, H. (2004). An investigation of the value of teaching profession among teacher-candidates and Turkish society. *Journal of Values Education, 2*(6), 35–49.

Kolb, D. (1984). *Experiential Learning: Experience as the source of learning and development*. Prentice-Hall.

Koparan, T., & Kaleli Yilmaz, G. (2015). The effect of simulation-based learning on prospective teachers' inference skills in teaching probability. *Universal Journal of Educational Research, 3*(11), 775–786.

Landriscina, F. (2017). Computer-supported imagination: The interplay between computer and mental simulation in understanding scientific concepts. In I. Levin & D. Tsybulsky (Eds.), *Digital tools and solutions for inquiry-based STEM learning* (pp. 33–60). IGI Global.

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education, 95*, 174–187.

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A Review of Literature. *Science Education, 103*(4), 799–822.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis*. Sage.

Ministry of National Education [MoNE]. (2013). *Preschool education curriculum for 36–72 months old children*. Ministry of National Education Publishing.

Ministry of National Education [MoNE] (2018). *Science curriculum (Primary and middle school 3, 4, 5, 6, 7 and 8th grades)*. Ankara.

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher, 45*(1), 18–35.

National Research Council (NRC). (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

National Science Teachers Association (NSTA). (2014). *NSTA position statement: Early childhood science education*. Retrieved from https://www.nsta.org/nstas-official-positions/early-childhood-science-education

Ong, E. T., Luo, X., Yuan, J., & Yingprayoon, J. (2020). The effectiveness of a professional development program on the use of STEM-based 5E inquiry learning model for science teachers in China. *Science Education International, 31*(2), 179–184.

Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd ed.). Sage Publication.

Petousi, V., & Sifaki, E. (2020). Contextualizing harm in the framework of research misconduct. Findings from a discourse analysis of scientific publications. *International Journal of Sustainable Development, 23*(3/4), 149–174.

Poultsakis, S., Papadakis, S., Kalogiannakis, M., & Psycharis, S. (2021). The management of digital learning objects of natural sciences and digital experiment simulation tools by teachers. *Advances in Mobile Learning Educational Research, 1*(2), 58–71.

Saylan Kirmizigul, A. (2019). *The comparison of computer-aided, activity-based and inquiry-based teaching approaches in science education.* Unpublished doctoral dissertation, Erciyes University, Kayseri.

Sripada, K. (2012). Neuroscience in the capital: Linking brain research and federal early childhood programs and policies. *Early Education & Development, 23*(1), 120–130.

Next Generation Science Standarts [NGSS]. (2017). *Topic arrangements of the Next Generation Science Standards.* https://www.nextgenscience.org/sites/default/files/AllTopic.pdf

Tastan Akdag, F., & Gunes, T. (2018). Using Algodoo in computer assisted teaching of force and movement unit. *International Journal of Social Sciences and Education Research, 4*(1), 138–149.

Tembo, T. M. T., & Lee, C.-S. (2017). *Using 2D simulation applications to motivate students to learn STEAM*. 25th International Conference on Computers in Education: Technology and Innovation: Computer-Based Educational Systems for the 21st Century, Workshop Proceedings, pp. 403–409.

Trey, L., & Khan, S. (2008). How science students can learn about unobservable phenomena using computer-based analogies. *Computers & Education, 51*(2), 519–529.

Ültay, N., & Aktaş, B. (2020). An example implementation of STEM in preschool education: Carrying eggs without breaking. *Science Activities, 57*(1), 16–24.

Urban, M. J., & Falvo, D. A. (2016). *Improving K-12 STEM education outcomes through technological integration.* Advances in early childhood and K-12 education book series. IGI Global.

Vidakis, N., Barianos, A. K., Trampas, A. M., Papadakis, S., Kalogiannakis, M., & Vassilakis, K. (2019). *In-Game raw data collection and visualization in the context of the "ThimelEdu" educational game.* International Conference on Computer Supported Education (pp. 629–646). Springer, Cham.

Wieselmann, J. R., Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2020). "I just do what the boys tell me": Exploring small group student interactions in an integrated STEM unit. *Journal of Research in Science Teaching, 57*(1), 112–144.

Wu, Y. T., & Anderson, O. R. (2015). Technology-enhanced stem (science, technology, engineering, and mathematics) education. *Journal of Computers in Education, 2*(3), 245–249.

Yıldırım, B. (2021). Preschool STEM activities: Preschool teachers' preparation and views. *Early Childhood Education Journal, 49*(2), 149–162.

Zigmont, J. J., Kappus, L. J., & Sudikoff, S. N. (2011). Theoretical foundations of learning through simulation. *Seminars in Perinatology, 35*(2), 47–51.

# Part II
# STEM in Early Childhood Education

# Chapter 6
# Digital Technology in Early STEM Education: Exploring Its Supportive Role

**Kleopatra Nikolopoulou**

**Abstract** The importance of early exposure to STEM has been reported by a number of scholars, while research indicated learning benefits when children use educational digital technologies. This chapter aims to explore the supportive-complementary role of educational digital technology (or ICT) in early childhood STEM education. Digital technology tools include educational robotics, simulations, models, narrative-rich videos, and digital games. Indicatively, educational robotics provides a learning environment where young children can apply computer programming skills, mathematical skills (numerical cognition, sequencing, patterns, counting, measuring, comparing, problem solving), and scientific skills and processes (scientific inquiry, conducting experiments, cause-effect relationships). The use of simulations enables hands-on experimental work and learning via investigations, while digital games aid children become familiar with the technology. Digital technology's support has the potential to enhance the benefits of STEM in early years, under conditions (teacher guidance, pedagogical strategies, etc.). It is suggested for teacher professional development to promote early STEM education with digital technology.

**Keywords** STEM · Digital technology · ICT · Early childhood · Preschool · Kindergarten

## 6.1 Introduction

STEM (Science, Technology, Engineering, Mathematics) education is an approach that presents in an integrated way the fields of science, technology, engineering, and mathematics (Çetin & Demircan, 2020; MacDonald & Huser, 2020). Major aspects of STEM education regard students working as a team to develop interaction between peers, engage in active learning, solve problems, make decisions and improve various skills such as creativity, critical thinking and self-esteem, enhance

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self-efficacy, scientific identity and an attitude towards mathematics and science (Hinojo-Lucena et al., 2020; Murphy et al., 2019); it has been pursued internationally since the mid-2000s. It is noted that the 'T' of 'Technology' in STEM acronym may include digital technology tools or not. Technology within STEM, is not confined to the use of digital technologies or electronic devices (McClure et al., 2017). The importance of early exposure to STEM has been reported by a number of scholars (e.g., Clements et al., 2021; Kalogiannakis & Papadakis, 2020; Wan et al., 2020). A STEM programme/curriculum in the early childhood education (ECE) can facilitate children's natural curiosity via, for example, appropriate, joyful, and playful experiments (experiential learning) and inquiry-based learning (MacDonald et al., 2020). The early years provide the basis for future learning in STEM as, for example, early experiences of science enhance children's self-belief in their ability to learn science, while mathematical skills developed at an early age could then predict academic performance (Campbell et al., 2018).

In parallel, today's children are born into a digital world, and from a very young age interact with different ICT tools, mainly in informal environments; thus, they become competent users of devices such as laptops, desktop computers, tablets, game consoles, communication based devices, without being formally instructed (Nikolopoulou, 2021a, 2021b). In the USA, the National Association for the Education of Young Children (NAEYC & FRC, 2012) reported on the use of technology and interactive media as tools to support-complement the development of young children. Information and Communication Technologies (ICT) usage by young children has been increased worldwide during the last years (Stephen & Edwards, 2018), while research studies regarding (educational) digital technology integration in ECE settings indicated positive outcomes on young children's learning and development (e.g., Clements & Sarama, 2003; McKenney & Voogt, 2012; Nikolopoulou, 2019). New digital and interactive technologies enable young children to develop skills and integrate knowledge about STEM subjects such as science, engineering (Kalogiannakis & Papadakis, 2020; Papadakis, 2020) and mathematics (Miller, 2018). Digital technology tools (e.g., apps and software) may offer challenges for STEM learning in ECE; the interactive nature of tablets and the multimodal features of apps (e.g., animations, audio, colorful graphics) have the potential to stimulate children's visual, auditory, kinesthetic and tactile senses, and deliver immediate feedback in different topics.

Taken into account the above (importance of early exposure to STEM and encouraging research findings regarding young children's learning/development via ICT), this study was initiated. Two major aspects/directions were considered in framing this study: (i) the interdisciplinary nature of STEM education, and (ii) the approach of learning with ICT, that is ICT as a tool to support learning objectives in different subjects (this approach is considered as more appropriate for ECE settings, in comparison to learning about ICT). The purpose of this study is to investigate the supportive–complementary role of educational digital technology in early STEM education. For the purpose of this paper the terms "(educational) digital technology" and "ICT" are treated as synonymous, including mobile technology as well. Twenty years ago the focus was predominantly on desktop computers, but later this was extended to tablets and interactive whiteboards as well (Jack & Higgins, 2019). Lately, different devices, toys, and resources (e.g., electronic musical keyboards, programmable interactive toys, mobile devices and apps, digital cameras, the internet, communication software) target young children (Stephen & Edwards, 2018); some of these, such as tablets, are very popular among children. Early childhood education (ECE or preschool) corresponds to the years before the attendance of elementary school. The significance (unique aspect) of this study lies in exploring the role of ICT across STEM fields; for example, the possibility of a simulation program regarding building bridges (i.e., an ICT tool) to support-complement learning objectives of an ECE interdisciplinary activity/project which combines science, mathematics and engineering (i.e., STEM fields).

## 6.2 Interdisciplinary Nature of STEM Education

STEM is an integrated approach to teach science, technology, engineering and mathematics. The goals-objectives of an early years STEM education programme regard knowledge-understanding, skills, dispositions, and feelings. Both STEM knowledge and skills are considered as flexible; examples of such skills include problem solving, creativity, hypothesising, self-investigating, and critical thinking (Poniszewska-Marańda et al., 2021). It is noted that the claims on STEM skills are not analogous to the empirical evidence: for example, although there is evidence on specific skills such as problem-solving and investigation, there is limited evidence on others such as the development of critical thinking skills. According to Murray (2019), STEM learning can promote important possibilities for building knowledge across disciplines, also incorporating Arts (STEAM) and Environmental Education (E-STEM); however, these disciplines are not the focus of this chapter. Wan et al. (2020) summarized research results on early childhood STEM education. They indicated that integrated STEM activities could be grouped into programming robots, traditional engineering design, digital game and comprehensive approach, while a challenge of conducting such activities with young children is to reduce cognitive load.

During integrated STEM learning, it is expected from children to handle information from different disciplines at the same time. When STEM approach is used in early childhood classrooms, young children can, for example; carry out hands-on activities in science to explore and observe different materials (to utilize them sooner in life); use scientific tools (e.g., microscope to observe fibers and threads); explore patterns and shapes, and build blocks (e.g., in mathematics); build/create 3-D structures with everyday materials (e.g., home and nature materials); build on their confidence levels and develop social learning skills. Yildirim (2021) examined preschool STEM classroom activities, lesson planning processes, and problems faced during the educational process. The findings revealed that teachers implemented different preschool STEM activities, while STEM training helped them to develop professional competence. According to teachers, preschool STEM activities included twenty-first century skills such as problem-solving skills, creativity and innovation, cooperation, communication, critical thinking, self-direction and responsibility, as well as scientific process skills.

Inquiry-based STEM activities provide young children with opportunities to practice skills such as reasoning, questioning, modeling and communication (Greca Dufranc et al., 2020). Basic science skills such as problem-solving, communicating, reasoning, estimating, testing, observing, measuring, comparing, grouping, classifying, making and testing predictions, asking and answering questions (Murray, 2019), are included in early STEM. Coding or computational thinking skills are included in STEM, and these could be exercised via the use of different digital technologies such as touch-screen tablets or robotics. Coding activities could also be achieved by using non-digital-technology means, such as paper and pencil.

Children's cognitive, social, and academic development should not be separated from play, because children actively explore and investigate the world using all their senses. As a consequence, early STEM learning could be improved through play. STEM concepts could be incorporated in ECE curriculum activities with water, blocks, and other materials that exist in the classroom. Exploration and scientific inquiry skills can also be exercised via ICT tools in combination with play-based approaches. For example, recent research (Lowrie & Larkin, 2020) has explored the role of digital technologies in play-based learning environments, into STEM activities. Hu and Yelland (2019) adopted the principles-practices inherent to STEM education to extend the role of new technologies in contemporary curricula and pedagogies; a characteristic was applying interdisciplinary knowledge in original learning contexts. As mentioned in the introduction, Technology within STEM may or may not include digital technology. STEM education with/via ICT in ECE settings is an under-researched field. Next section aims to explore the role of educational digital technology (ICT) as supportive tool/medium within and across STEM subjects.

## 6.3 ICT as Supportive Tool in Early STEM Teaching and Learning

ICT tools (collaborative technologies, online games, software/apps, digital content, devices and hardware, etc.) may impact on many aspects of STEM education, such as improving teacher competencies, enhancing the learning resources, and facilitating student and teacher motivation (Debry & Gras-Velazquez, 2016); according to the researchers, ICT has the potential to supplement existing pedagogical approaches such as project-based, experiential and inquiry-based learning. Hwang et al. (2020) reported that mobile-ubiquitous technologies are potential facilitators for students' learning across contexts, while their use could provide new perspectives and possibilities for developing STEM activities. Pasnik and Hupert (2016) reported that STEM learning and teaching in early years can be enhanced if technology is used, for example, to: (i) expose children to phenomena, different types of information that they might not otherwise have access to (e.g., observing processes/situations not easily carried out in the classroom, recording data), (ii) facilitate children's development of early science skills and practices, and (iii) engage children in activities through which they can collaborate, share ideas and discuss (e.g., by using a program in small-groups). Effects of ICT in STEM education were shown by the European Schoolnet report (2017), for primary education; it was indicated that ICT, among others, facilitates understanding of concepts and processes, interactivity, innovation (e.g., handling topics that interest children), independent learning, and interactions (student–student, student–teacher).

In parallel, research revealed that digital technologies' usage affects positively specific STEM subjects or skills. Research reported on children's early mathematics learning (Gray et al., 2017; Papadakis et al., 2018), on skills such as counting (Reeves et al., 2017), classification, seriation and counting (Zaranis & Valla, 2019), as well as on early science learning (McClure et al., 2017) and problem-solving skills (Herodotou, 2017). Examples of learning activities carried out in early mathematics with the support of digital technology included serialization-sorting of objects, learning of time and space concepts, familiarization with numbers, classification, matching, as well as activities with shapes, colors, and memory cards (Nikolopoulou, 2020). Robotics, mathematics, and STEM provide most opportunities in early childhood, especially regarding the cultivation of interests early in computing (Dorouka et al., 2020).

Educational robotics provides a learning environment that combines hands-on experiences and play with the integration of educational digital technologies (programming robots lies in the foundation of digital technologies). During the process of educational robotics children can apply computer programming, computational thinking skills (Papadakis, 2020, 2021; Papadakis & Kalogiannakis, 2020), mathematical skills (e.g., numerical cognition, sequencing, patterns, counting, measuring, comparing, problem solving), as well as scientific skills and processes (e.g., scientific inquiry, conducting experiments, cause-effect relationships, problem-solving). Misirli and Komis (2014) indicated that kindergarten children using programmable toys could exercise mathematical skills such as measurement, spatial orientation and sequencing skills. Mathematical thinking capabilities can be blended with computational thinking capabilities to solve a problem. For example, Kotsopoulos et al., (2019) reported that in a treasure activity, when children were asked to give explanations to their teacher, they used words such as "first," "then," "next," and "last." Similarly, young children develop creativity and problem-solving skills via computation thinking activities (Bers, 2018). Practices that use STEM and robot-based approaches (including code-learning) can enhance scientific literacy (Greca Dufranc et al., 2020) and scientific process skills (Turan & Aydoğdu, 2020). Robotics enable programming activities to be carried out, thus providing possibilities for the integration of STEM fields into the classroom, and engage children with engineering and technology (Çetin & Demircan, 2020). Although STEAM (the 'A' for arts) is not the focus of this chapter, it is mentioned that this approach was applied by integrating educational robotics with scientific, digital and artistic perspectives (Manera, 2020), and also within robotics curriculum to teach both engineering and programming; in the latter study, the findings revealed mastery of basic programming concepts (Sullivan & Bers, 2018).

Programs such as simulations and modelling can facilitate-support teaching and learning STEM in early years as well. Simulation is usually constructed with an underlying model that is based on some real-world behavior or natural/scientific phenomena such as models of the ecosystem or a simulated flight. When a real experiment is difficult or impossible to be performed in the classroom (due to scale, cost, danger, etc.), simulations provide the opportunity for children to experience phenomena they would not be able to see/practice otherwise. Technological developments promote increased engagement with science, providing opportunities for participation and learning; e.g., by using simulations, children engage with experiments and can learn through trial and error, exploration and experimentation (Scanlon et al., 2019). Within the context of science and engineering children can use ready models or construct their own so as to represent different situations; diagrams, mathematical representations, or computer simulations can be included. Scientific models provide opportunities for children to use inquiry skills, explain phenomena based on the data they collected through their own experiments, and solve problems; thus, exercising skills in both science and mathematics.

Also, narrative-rich videos or mobile apps can provide access to information that is otherwise invisible: causes and effects of sea pollution, how the force of the wind moves the ships, seeds growing into plants. Well-designed educational digital games could aid children become familiar with the technology and also develop and exercise STEM, science and mathematics skills-concepts (sometimes at the same time). However, with regard to the development of critical thinking skills in ECE digital educational environments, the research evidence is very limited. In the study of Behnamnia et al., (2020) preschool children used educational digital games where children had opportunities to engage in creative thinking; the utilization of games had the potential for children to develop creative and critical thinking skills, technological skills and positive attitude to learning. Vogt and Hollenstein (2021) indicated the potential of pretend play in areas of digital transformation (such as robotics) for children to develop digital skills, creativity, communication, collaboration, critical thinking and problem solving skills. Schroeder and Kirkorian (2016) examined the extent to which familiarity and interactivity influence preschoolers' learning from STEM digital games. The games were based on a popular TV show and were designed to test STEM related skills (numerical cognition, and knowledge of the concept of growth); the findings were related to age, familiarity and conditions such as watching or playing the game.

3D virtual worlds in virtual learning environments could help children to construct situations that resemble realistic ones, allowing them to develop and exercise their skills. Forbes et al. (2021) examined learning processes and outcomes from using 3D design and printing technologies with children aged 5–8 years; it was found that children developed various skills such as technology skills, problem solving, design thinking, collaboration, and communication (thus, these tools could be used within STEM practices-activities). Other types of digital technologies such as Kitsi blocks (an Australian developed digital technology platform) were reported as successful in integrated STEM projects for mathematics (Easton et al., 2020); the researchers described how contextualised integrated STEM projects can bring mathematics into the foreground with digital technologies. Also a recent technology, the Internet of Toys, could also be linked to children's STEM-focused learning, since children may be engaged in design play in early childhood settings.

A combination of educational digital tools could support and complement early STEM learning. Indicatively, when studying climate change via the utilization of educational videos, simulations and tablet-based digital games. Teachers can stimulate children's interest by asking the right questions (e.g., when watching the videos), engage them in making predictions, comparisons and testing ideas/hypotheses (e.g., while using the simulations or games), and also encouraging children to observe their natural environment and find interrelationships. Digital technology, apart from familiarizing children with technological skills, provides opportunities for exploration, discovery, research, problem-solving, as well as for communication and collaboration.

Quality educational technology tools have the potential to support early STEM learning. Experiences that could be provided to young children, include: to engage young children intellectually, to encourage them to collaborate and interact through discussions, to plan tasks/experiments, as well as to take initiatives in different activities. In science, testing which everyday objects float and sink could be facilitated with ICT apps/software. Children can also experience STEM in the arts or reading, and technology could also support relevant goals (e.g., when children are exposed to concepts, vocabulary, and experiences of developmentally appropriate STEM activities).

As indicated above, the benefits of STEM in early years (exercise/development of skills and competencies, learning of concepts, etc.) can be enhanced with the assistance of educational digital technologies (ICT tools) in early childhood education settings. However, these benefits arise under certain conditions (e.g., teacher guidance, pedagogical strategies, infrastructure, technical and administrative assistance), the central one being the teacher's role (discussed in next section); even the best-designed technology tools/apps cannot replace human interaction or good teaching.

## 6.4 Teachers' Role in the STEM—Digital Technology Environment

The role of the teachers is very important in young children's learning. In the STEM—educational digital technology environment the teachers, for example, plan the classroom environment and the materials they use, they choose developmentally appropriate programs/software to enhance children's learning, they ask questions to prompt higher order thinking (where even the youngest children benefit), and they encourage children to play and explore (e.g., stepping back, observing and encouraging them to see how the tools work). Teachers can set the learning environment/context where children will engage with scientific phenomena—practices, and exercise different skills. Well-planned and structured uses of ICT can support and complement children's learning in ECE settings; offering developmentally appropriate content and support of STEM learning. The teachers are central even when the software/apps are of good quality; they will scaffold children's interactions with apps by helping them make meaning of, for example, new concepts. Technology-supported pedagogical practices/approaches will eventually help children benefit from early STEM learning.

There is research evidence regarding teachers' views and practices in the early STEM environment. For example, a recent review (Wan et al., 2020) indicated that teachers' views of STEM education in the ECE environments varied: teachers viewed STEM as separate disciplines, as an integrated approach, some disagreed to its necessity for ECE settings, while practical obstacles (e.g., time, administrative support, resources) and concerns (e.g., children's interest, safety) were also expressed. Studies reported that many teachers express anxiety, low self-confidence, and gendered perceptions on STEM themes, which might affect their students (McClure et al., 2017), and that teachers struggle with the adoption and application of digital technologies in STEAM education (Adov et al., 2020). Ndijuye and Tandika (2020) reported that preschool teachers' views on what is STEM education for young children were vague; teachers could guide their students and aid them in science and mathematics, but they were not aware (and there were no guidelines) about how to aid children's learning in technology or engineering. Professional development programmes and relevant training were shown to increase teachers' confidence in teaching STEM (MacDonald et al., 2020) and pre-service teachers' STEM self-efficacy (Chen et al., 2021), respectively. The above, necessitate the role of professional development. Early childhood teachers may need assistance to foster early STEM learning/education with ICT, and professional development can play a vital role on this issue.

Teachers are suggested to facilitate a broad role of STEM education for young children, since formal ECE settings can be dynamic environments to promote early STEM development (Hachey, 2020). Since the link-relationship of digital technology use and play is a field of research and of current interest to educators (Nikolopoulou & Gialamas, 2015; Stephen & Edwards, 2018), teachers can benefit from reconsidering STEM within the context of play-based and digital technology-supported learning environments. As a consequence, teacher training programmes should include STEM content, relevant research findings, as well as quality digital technology-enhanced experiences/practices and pedagogies. Specific educational objectives of early STEM learning activities could incorporate aspects of ICT as a tool. Besides, school-home links could be enhanced. Since children's interactions with adults are important for their learning, technology could also help the establishment of links between school, home, and other semi-formal learning contexts (such as museums), to support STEM learning for youngsters (McClure et al., 2017).

## 6.5 Concluding Remarks and Future Research Questions

Although young children grow up in the world of digital technology, ICT applications are used less frequently in formal ECE settings in comparison to informal/home settings (Nikolopoulou, 2020; Parette et al., 2010). Appropriate software, mobile apps and online educational material can benefit, support and enrich early science and mathematics learning, provided these are integrated-used in developmentally appropriate ways. Educational digital technology tools provide opportunities that enable children to investigate the benefits of ICT in play-based learning contexts, while digital technology could contribute to integrated STEM approach. However, its supportive and complementary role cannot replace human interaction, and this makes essential the teacher's role. The teachers are expected to scaffold and guide children's interactions with digital technology tools, to enrich their STEM learning in the digital environment. Another issue (beyond the scope of this chapter) regards the development of digital tools (educational robotics, simulations, digital games, etc.), in that these must be designed taken into account that teachers play a key role as facilitators of ICT learning experiences. It is a precondition, that digital resources are to be evaluated by teachers before their utilization in the classroom.

As the boundaries between different technologies are constantly being revised and the capabilities of ICT tools are improving (e.g., mobile devices have increasingly more sophisticated features), future research is suggested to investigate which specific features of educational apps/software (Nikolopoulou, 2007) and how different ICT tools-applications could support early STEM learning. For example, recent research examined the impact of (interactive) haptic feedback, via the tablet, on children's learning of STEM concepts from mobile devices and apps (Pila et al., 2020). Also, the Internet of Toys (internet-connected toys) is a new technological innovation that targets young children, but its educational value has not yet been established at home or in ECE settings (Nikolopoulou, 2021b). More research evidence is needed on children's development of specific STEM skills such as critical thinking, in educational digital environments/contexts.

Taken into consideration this chapter's issues/discussion, indicative research questions for future research include:

- What educational digital technology tools (and experiences) are most likely to support, complement and enhance early STEM learning?
- What are the predominant directions for the design of ECE STEM curricula/activities? (e.g., for twenty-first century skills development)
- How could ECE teachers' professional development (as well as student-teachers' training) assist teachers in teaching STEM topics via ICT support?
- What is the role of stakeholders (e.g., policy makers, curriculum developers, education consultants) in supporting children's engagement with ICT in early STEM?
- What are the lessons learnt from research and educational policies in different countries that successfully applied early STEM (so as to build upon them)?

## References


Adov, L., Pedaste, M., Leijen, A., & Rannikmäe, M. (2020). Does it have to be easy, useful, or do we need something else? STEM teachers' attitudes towards mobile device use in teaching. *Technology, Pedagogy and Education, 29*(4), 511–526.

Behnamnia, N., Kamsin, A., Ismail, M.A.B., & Hayati, A. (2020). The effective components of creativity in digital game-based learning among young children: A case study. *Children and Youth Services Review, Elsevier*, 116(C), 105227.

Bers, M. U. (2018). Coding and computational thinking in early childhood: The impact of ScratchJr in Europe. *European Journal of STEM Education, 3*(3), 08.

Campbell, C., Speldewinde, C., Howitt, C., & MacDonald, A. (2018). STEM practice in the early years. *Creative Education, 9*(1), 11–25. https://doi.org/10.4236/ce.2018.91002

Çetin, M., & Demircan, H. Ö. (2020). Empowering technology and engineering for STEM education through programming robots: A systematic literature review. *Early Child Development and Care, 190*(9), 1323–1335.

Chen, Y. L., Huang, L. F., & Wu, P. C. (2021). Preservice preschool teachers' self-efficacy in and need for STEM education professional development: STEM pedagogical belief as a mediator. *Early Childhood Education Journal, 49*, 137–147.

Clements, D., & Sarama, J. (2003). Strip mining for gold: Research and policy in educational technology—A response to 'Fool's Gold.' *Educational Technology Review, 11*(1), 7–69.

Clements, D. H., Vinh, M., Lim, C. I., & Sarama, J. (2021). STEM for Inclusive Excellence and Equity. *Early Education and Development, 32*(1), 148–171.

Debry, M, & Gras-Velazquez, A. (2016). *ICT tools for STEM teaching and learning*. Transformation Framework. Microsoft.

Dorouka, P., Papadakis, S., & Kalogiannakis, M. (2020). Tablets and apps for promoting robotics, mathematics, STEM education and literacy in early childhood education. *International Journal of Mobile Learning and Organization, 14*(2), 255–274.

Easton, G., Wellington, A., Davis, J., & Yeh, A. (2020). Foregrounding mathematics in integrated STEM projects via digital technology. *Australian Mathematics Education Journal, 2*(3), 10–15.

European Schoolnet (2017). *ICT in STEM Education—Impacts and Challenges: On students.* A STEM Alliance Literature Review. Brussels.

Forbes, A., Falloon, G., Stevenson, M., Hatzigianni, M., & Bower, M. (2021). An analysis of the nature of young students' STEM learning in 3D technology-enhanced makerspaces. *Early Education and Development, 32*(1), 172–187. https://doi.org/10.1080/10409289.2020.1781325

Gray, C., Dunn, J., Moffett, P., & Mitchell, D. (2017). *Mobile devices in early learning: Evaluating the use of portable devices to support young children's learning*. Report commissioned by Irish Education Authority.

Greca Dufranc, I.M., García Terceño, E.M., Fridberg, M., Cronquist, B. & Redfors, A. (2020). Robotics and early-years STEM education: the botSTEM framework and activities. *European Journal of STEM Education*, 5(1), 01. https://doi.org/10.20897/ejsteme/7948

Hachey, A. C. (2020). Success for all: Fostering early childhood STEM identity. *Journal of Research in Innovative Teaching & Learning, 13*(1), 135–139. https://doi.org/10.1108/JRIT-01-2020-0001

Herodotou, C. (2017). Young children and tablets: A systematic review of effects on learning and development. *Journal of Computer Assisted Learning, 34*(1), 1–9.

Hinojo-Lucena, F. J., Dúo-Terrón, P., Navas-Parejo, M. R., Rodríguez-Jiménez, C., & Moreno-Guerrero, A. J. (2020). Scientific performance and mapping of the term STEM in education on the web of science. *Sustainability, 12*, 2279. https://doi.org/10.3390/su12062279

Hu, X., & Yelland, N. (2019). Changing learning ecologies in early childhood teacher education: From technology to stem learning. *Beijing International Review of Education, 1*(2–3), 488–506. https://doi.org/10.1163/25902539-00102005

Hwang, G. J., Li, K. C., & Lai, C. L. (2020). Trends and strategies for conducting effective STEM research and applications: A mobile and ubiquitous learning perspective. *International Journal of Mobile Learning and Organisation, 14*(2), 161–183.

Jack, C., & Higgins, S. (2019). What is educational technology and how is it being used to support teaching and learning in the early years? *International Journal of Early Years Education, 27*(3), 222–237. https://doi.org/10.1080/09669760.2018.1504754

Kalogiannakis, M. & Papadakis, S. (2020). The use of developmentally mobile applications for preparing pre-service teachers to promote STEM activities in preschool classrooms. In St. Papadakis & M. Kalogiannakis (Eds) *Mobile Learning Applications in Early Childhood Education* (pp. 82–100). IGI Global. https://doi.org/10.4018/978-1-7998-1486-3.ch005.

Kotsopoulos, D., Floyd, L., Nelson, V., & Makosz, S. (2019). Mathematical or computational thinking? An early years perspective. In K.M. Robinson et al. (Eds.), *Mathematical Learning and Cognition in Early Childhood* (pp. 79–90). Springer Nature. https://doi.org/10.1007/978-3-030-12895-1_6

Lowrie, T., & Larkin, K. (2020). Experience, represent, apply (ERA): A heuristic for digital engagement in the early years. *British Journal of Educational Technology, 51*(1), 131–147.

MacDonald, A., & Huser, C. (2020). Making STEM Visible in Early Childhood Curriculum Frameworks. In A. MacDonald, L. Danaia, & S. Murphy (Eds.) *STEM Education Across the Learning Continuum*. Springer. https://doi.org/10.1007/978-981-15-2821-7_6

MacDonald, A., Huser, C., Sikder, S., & Danaia, L. (2020). Effective early childhood STEM education: Findings from the little scientists evaluation. *Early Childhood Education Journal, 48*, 353–363. https://doi.org/10.1007/s10643-019-01004-9

Manera, L. (2020). STEAM and educational robotics: Interdisciplinary approaches to robotics in early childhood and primary education. In F. Ferraguti, V. Villani, L. Sabattini, & M. Bonfè (Eds.) *Human-friendly robotics 2019. HFR 2019. Springer proceedings in advanced robotics,* vol. 12. Springer. https://doi.org/10.1007/978-3-030-42026-0_8

McClure, E. R., Guernsey, L., Clements, D. H., Bales, S. N., Nichols, J., Kendall-Taylor, N., & Levine, M. H. (2017). *STEM starts early: Grounding science, technology, engineering, and math education in early childhood*. The Joan Ganz Cooney Center at Sesame Workshop.

McKenney, S., & Voogt, J. (2012). Teacher design of technology for emergent literacy: An explorative feasibility study. *Australasian Journal of Early Childhood, 37*(1), 4–12.

Miller, T. (2018). Developing numeracy skills using interactive technology in a play-based learning environment. *International Journal of STEM Education*, 5(39). https://doi.org/10.1186/s40594-018-0135-2

Misirli, A., & Komis, V. (2014). Robotics and programming concepts in early childhood education: A conceptual framework for designing educational scenarios. In Research on e-learning and ICT in education. Springer. https://doi.org/10.1007/978-1-4614-6501-0_8

Murphy, S., MacDonald, A., Danaia, L., & Wang, C. (2019). An analysis of Australian STEM education strategies. *Policy Futures in Education, 17*(2), 122–139.

Murray, J. (2019). Routes to STEM: Nurturing science, technology, engineering and mathematics in early years education. *International Journal of Early Years Education, 27*(3), 219–221. https://doi.org/10.1080/09669760.2019.1653508

National Association for the Education of Young Children (NAEYC), & Fred Rogers Center (FRC) (2012). *Technology and interactive media as tools in early childhood programs serving children from birth through age 8.* Retrieved February 3, 2021, from http://www.naeyc.org/content/technology-and-young-children.

Ndijuye, L. G., & Tandika, P. B. (2020). STEM starts early: Views and beliefs of early childhood education stakeholders in Tanzania. *Journal of Childhood, Education & Society, 1*(1), 29–42. https://doi.org/10.37291/2717638X.20201128

Nikolopoulou, K. (2007). Early childhood educational software: Specific features and issues of localization. *Early Childhood Education Journal, 35*(2), 173–179. https://doi.org/10.1007/s10643-007-0168-5

Nikolopoulou, K. (2019). Mobile technologies and early childhood education. In M. Tsitouridou, J.A. Diniz, & T. Mikropoulos (Eds.) *Technology and Innovation in Learning, Teaching and Education.* TECH-EDU 2018, CCIS 993 (pp. 444–457). Springer Nature. https://doi.org/10.1007/978-3-030-20954-4_33

Nikolopoulou, K. (2020). Preschool teachers' practices of ICT-supported early language and mathematics. *Creative Education, 11*(10), 2038–2052. https://doi.org/10.4236/ce.2020.1110149

Nikolopoulou, K. (2021). Mobile devices in early childhood education: Teachers' views on benefits and barriers. *Education and Information Technologies, 26*(1), 3279–3292. https://doi.org/10.1007/s10639-020-10400-3

Nikolopoulou, K. (2021b). Internet of toys for young children: Educational value or threat? In St. Papadakis & M. Kalogiannakis (Eds.) *Handbook of research on using educational robotics to facilitate student learning* (pp. 424–439). IGI Global. DOI: http://doi:https://doi.org/10.4018/978-1-7998-6717-3.ch017

Nikolopoulou, K., & Gialamas, V. (2015). ICT and play in preschool: Early childhood teachers' beliefs and confidence. *International Journal of Early Years Education, 23*(4), 409–425.

Papadakis, S. (2020). Evaluating a teaching intervention for teaching STEM and programming concepts through the creation of a weather-forecast app for smart mobile devices. In M. Kalogiannakis & S. Papadakis (Eds.) *Handbook of research on tools for teaching computational thinking in P-12 education* (pp. 31–53). IGI Global. http://doi:https://doi.org/10.4018/978-1-7998-4576-8.ch002

Papadakis, S. (2021). The impact of coding apps to support young children in computational thinking and computational fluency A literature review. *Frontiers in Education, 6*, 657895. https://doi.org/10.3389/feduc.2021.657895

Papadakis, S., & Kalogiannakis, M. (2020). Learning computational thinking development in young children with Bee-Bot educational robotics. In *Handbook of research on tools for teaching computational thinking in P-12 education.* IGI Global. DOI: https://doi.org/10.4018/978-1-7998-4576-8.ch011

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018). The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece. *Education and Information Technologies*, 23(5), 1849–1871.

Parette, H., Quesenberry, A., & Blum, C. (2010). Missing the boat with technology usage in early childhood settings: A 21st century view of developmentally appropriate practice. *Early Childhood Education Journal, 37*(5), 335–343. https://doi.org/10.1007/s10643-009-0352-x

Pasnik, S., & Hupert, N. (2016). *Early STEM learning and the roles of technologies*. Education Development Center.

Pila, S., Piper, A. M., Lauricella, A., & Wartella, E. (2020). Preschoolers' STEM learning on a haptic enabled tablet. *Multimodal Technologies and Interactions, 4*(4), 87.

Poniszewska-Marańda, A., Szukalska, A., & Wilczyński, Ł. (2021). Learner-centred pedagogical approach based on smart city concept to enhance the development of STEM skills of children. In L. Barolli, A. Poniszewska-Maranda, & T. Enokido (Eds.) *Complex, intelligent and software intensive systems. CISIS 2020. Advances in intelligent systems and computing*, 1194. Springer. https://doi.org/10.1007/978-3-030-50454-0_20

Reeves, J., Gunter, G., & Lacey, C. (2017). Mobile learning in pre-kindergarten: Using student feedback to inform practice. *Educational Technology & Society, 20*(1), 37–44.

Scanlon, E., Herodotou, C., Whitelock, D., & Edwards, C. (2019). STEM learning: Foundations. In R. Ferguson, A. Jones & E. Scanlon (Eds.) *Educational visions: lessons from 40 years of innovation* (pp. 127–138). Ubiquity Press. DOI: https://doi.org/10.5334/bcg.h

Schroeder, E. L., & Kirkorian, H. L. (2016). When seeing is better than doing: Preschoolers' transfer of STEM skills using touchscreen games. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2016.01377

Stephen, C., & Edwards, S. (2018). *Young children playing and learning in a digital age: A cultural and critical perspective*. Routledge.

Sullivan, A., & Bers, M. U. (2018). Dancing robots: Integrating art, music, and robotics in Singapore's early childhood centers. *International Journal of Technology and Design Education, 28*, 325–346. https://doi.org/10.1007/s10798-017-9397-0

Turan, S., & Aydoğdu, F. (2020). Effect of coding and robotic education on pre-school children's skills of scientific process. *Education and Information Technologies, 25*(5), 4353–4363. https://doi.org/10.1007/s10639-020-10178-4

Vogt, F., & Hollenstein, L. (2021). Exploring digital transformation through pretend play in kindergarten. *British Journal of Educational Technology*. https://doi.org/10.1111/bjet.13142

Wan, Z. H., Jiang, Y., & Zhan, Y. (2020). STEM education in early childhood: A review of empirical studies. *Early Education and Development*. https://doi.org/10.1080/10409289.2020.1814986

Yildirim, B. (2021). Preschool STEM activities: Preschool teachers' preparation and views. *Early Childhood Education Journal, 49*, 149–162. https://doi.org/10.1007/s10643-020-01056-2

Zaranis, N., & Valla, V. (2019). Tablets in learning mathematics for kindergarten students. In L. Daniela (Ed.) *Didactics of smart pedagogy*. Springer.

# Chapter 7
# A Systematic Literature Review on STEM Research in Early Childhood

**Sokratis Tselegkaridis and Theodosios Sapounidis**

**Abstract** Nowadays, Science, Technology, Engineering, and Mathematics (STEM) tools are used in many schools promoting formal and informal learning. STEM framework covers the educational needs of various age-groups starting from preschool up to university. With this framework, students develop knowledge and skills while dealing with real-world problems. In the previous years, several reviews have been published aimed at STEM studies. Nevertheless, these reviews do not investigate a specific age group. Thus, the present book chapter is a systematic literature review on STEM research in early childhood, focusing on STEM studies for students under 8 years old. For this purpose, the chapter includes articles, which were emerged from search keys in six scientific databases. The review presents some major characteristics of the studies such as: (a) the number of participants in the intervention (sample size), (b) the intervention objectives, (c) the size of groups, (d) the equipment type, (e) the materials used, and (f) the type of research design. According to the findings, among others, STEM education in early childhood seems to successfully meet the teaching objectives, the group size is usually between 2 and 4 students, the long-term studies are absent and the quantitative methods are limited.

**Keywords** STEM research · Early childhood · Educational intervention

## 7.1 Introduction

The usage of robots as an educational tool is not a recent approach. In the late 1970s, Papert's idea to use robots to promote learning was the basis of educational robotics (ER) (Chevalier et al., 2020). Robots in education offer students new ways to play and learn, fostering students' cognitive and social skills (Ioannou & Makridou, 2018). Therefore, they are excellent learning tools in the field of Science, Technology, Engineering, and Mathematics (Cervera et al., 2020). It is essential for students and

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teachers to be aware of the available tools along with the benefits and implications of STEM education, mainly because teachers can make learning easier and more efficient, while guiding students to develop digital and soft skills (Angeli & Valanides, 2020; Chiazzese et al., 2019; Sapounidis & Alimisis, 2020; Sapounidis et al., 2016; Tselegkaridis & Sapounidis, 2021).

Creativity, Computation Thinking (CT), adaptability are such kind of skills as well as the ability to work with and within a group (Nemiro, 2020). It is important for children to develop these skills so they can cope with difficulties during their adult life (Julià & Antolí, 2016). Therefore, Li et al. (2020) say that particular CT skills should be deemed "*as a model of thinking that is more about thinking than computing*". In general, a student can learn and develop skills and CT, while designing mechanisms and program robots. The adaptation of STEM technologies in education appears to be significantly benefited by the fact that students are more interested and motivated in learning (Newton et al., 2020). In addition, it is pointed out that collaborative learning in STEM has cognitive, social, and metacognitive benefits for students (Sapounidis et al., 2019a, 2019b).

At the moment, the use of STEM programs in education is widespread. Through these programs, students might acquire knowledge and develop skills. However, the variety of the educational approaches and the age range of the students may lead to different conclusions about the effectiveness of the STEM programs (Johnson, 2003). For this reason, it is necessary to study the STEM programs under the lenses of a specific age group so that the conclusions might be safer. Thus, based on the need for empirical validation of STEM education in order to enlighten the possible benefits, this chapter deals with STEM research in early childhood with students under the age of 8 years old. In particular, a systematic literature review was conducted recording several features of STEM research, such as the activities in which students participated, for example, building a robot using physical or virtual manipulatives.

The rest of the article is organized as follows: Background and STEM research complete the Introduction by describing the framework of the article. Subsequently, the procedure followed for the systematic literature review is described. Also, in Measurements the categorizations of the features of the studies are recorded. In the next section presents the Findings of our review. Follows a discussion about the findings of the literature. Finally, the Conclusions are recorded.

### *7.1.1 Background*

In recent years, many studies have been done on the effects of STEM education. Consequently, several reviews have tried to categorize the STEM studies aiming to explore the potential benefits of this new way of teaching. Some representative reviews are: (a) Gao et al. (2020) found that although many curricula aimed at interdisciplinary topics, most assessments are monodisciplinary, (b) Cutumisu et al. (2019) found that most studies used multiple-choice questions, (c) Xia and Zhong (2018) found that observation and questionnaires used as main measurement tools,

(d) Anwar et al. (2019) addressed the benefits of STEM education, and their findings showed that ER is a useful tool for learning even for students with no interest in STEM topics, (e) Benitti's (2012) findings showed that main subject were mathematics and physics, and (f) Tlili et al. (2020) referred to special education and identifies the necessity for a stronger link between the design of a STEM program and the needs of a child with a disability.

These reviews provide useful information, nevertheless, they are not aimed at a specific age group, but at K–12 education in general. The field of research around STEM education in early childhood is recent, thus there are not many articles with literature reviews. However, three of them are listed below.

Ata Aktürk and Demircan (2017) reviewed STEM and STEAM (Science, Technology, Engineering, Arts, and Mathematics) education in early childhood. For this study six databases were used. The search included articles from 2006 to 2016 and 22 articles emerged. The findings showed that from 2013 onwards there is an increase in published articles on STEM research in early childhood. In addition, 27.2% of research focused on engineering, while only 13.6% on robotics and programming. Also, 68.75% of the participants were children 3–6 years old. Finally, 56.2% of studies were conducted in the USA.

Çetin and Demircan (2020) used nine databases and 23 articles extracted. The search focused on articles related to robot programming activities for children up to 8 years old. The authors, after a descriptive analysis of the articles, concluded that robotic programming activities can be a useful tool for young children to acquire knowledge.

Wan et al. (2020) used three databases and 24 articles extracted. The findings showed that the age of the students was from 3 to 8 years old, 79.1% of the studies were conducted in the USA, 62.5% of the articles were published in 2018, while no article was published before 2013. Finally, the findings showed that students were interested and willing to collaborate in STEM learning.

In these reviews, there are restrictions, such as the use of articles from a specific time period. Furthermore, the literature review on STEM education in early childhood is quite limited. Therefore, this book chapter tries to serve mostly as a practical guide and a basis for future research that enriches the current STEM agenda in early childhood, providing many important aspects of the studies such as the size of the sample, the study design, the duration of the study, the activities/tasks for participants, the materials used, the accumulated data type (qualitative/quantitative), and their findings.

### *7.1.2 STEM Research*

STEM education is the combination of science, technology, engineering and mathematics aiming to improve the educational process. STEM research explores mostly students' knowledge, attitudes, or/and skills. Research is currently being conducted in many countries, from the United States (e.g. Ching et al., 2019) to Italy (e.g.

Chiazzese et al., 2019) and Singapore (e.g. Sullivan & Bers, 2018), demonstrating the potential of STEM education. The studies are conducted from kindergartens (e.g. Angeli & Valanides, 2020) to high schools (e.g. Chapman et al., 2020), that is, STEM education is applied to a wide range of student ages. In addition, the subject may be related to robotics (e.g. Julià & Antolí, 2016), or even other subjects, such as history (e.g. Ioannou & Ioannou, 2020).

Additionally, intervention objectives can be a combination of knowledge, skills, and attitudes (e.g. Arfé et al., 2020; Demetriadis et al., 2015). The research may last from 15 min (e.g. Konijn & Hoorn, 2020), up to over 2000 (e.g. Newton et al., 2020). There are studies where students do not form groups (e.g. Master et al., 2017), while other studies use up to 5 children in the same group (e.g. Muñoz et al., 2020). The activities in which students participate are usually programming, engineering, or their combination (e.g. Sisman et al., 2020). The type of equipment can be software (e.g. Sung et al., 2017), or a real wheeled or modular robot (e.g. Chevalier et al., 2020). The robotic system can be programmed either via Tangible User Interface (TUI), Graphical User Interface (GUI) or both (e.g. Sullivan & Bers, 2013; Sapounidis et al., 2019a, 2019b).

There are studies where the accumulated data type is qualitative, quantitative, or even the combination of the two (e.g. Baek et al., 2019), while their recording can be done in multiple ways such as questionnaire, video, interview, observation (e.g. Newton et al., 2020). Finally, it seems that STEM education offers benefits to students of all levels (Johnson, 2003), nevertheless, there are some cases where there is no significant gain or advance (e.g. Julià & Antolí, 2016).

Therefore, STEM studies might consist of multiple stages and focus on different domain and topics. However, in this review article we have recorded their main aspects, such as:

- The age of students and the school level (kindergarten or primary) where the research took place
- The sample size and the groups' size formed by the students
- The subject (e.g. robotics, or computer science) and the duration of the experiment
- The activities in which the students participated (e.g. programming a line follower or building a robot using physical manipulatives)
- The intervention objectives. These objectives show where the researchers focused (e.g. knowledge, skills, or attitudes)
- The type of equipment used by the students (e.g. wheeled robot, or software application)
- The study design. The design of a study may contain posttest, pretest, observations, and interviews
- How the robotic system is programmed. This can be TUI or GUI
- The data sources (e.g. through video or written evaluation) and the data analysis: qualitative (e.g. observation or interview) or/and quantitative (questionnaires)
- The results of the intervention.

## 7.2 Methods

The purpose of this book chapter is to investigate various aspects of STEM education in early childhood. Thus, a systematic literature review was carried out to emerge articles for studies with children under 8 years old.

### *7.2.1 Procedure*

A systematic literature review was undertaken in January 2021, in the following six databases:

- Scopus
- SpringerLink
- ERIC
- IEEEXplore
- ScienceDirect
- DOAJ.

The «(*primary OR elementary*) *AND* (*educational OR education*) *AND* (*robotics OR robots*) *AND* (*STEM*)» were used as search-string. Searches were performed without a specific time range. Table 7.1 shows the inclusion–exclusion criteria.

Based on the search keywords, 202 articles were extracted (see Table 7.2). Then, 179 articles were excluded, as long as they did not contain studies for STEM education

**Table 7.1** Inclusion—exclusion criteria

| Search keyword | Inclusion criteria | Exclusion criteria |
|---|---|---|
| (Primary OR elementary) AND (educational OR education) AND (robotics OR robots) AND (STEM) | Study for STEM education with children under 8 years old | Study for STEM education with children above 8 years old |

**Table 7.2** Databases and results

| Database | Articles | Exclude | Include | Duplicated | Unique |
|---|---|---|---|---|---|
| Scopus | 40 | 36 | 4 | 0 | 4 |
| SpringerLink | 83 | 72 | 11 | 2 | 9 |
| ERIC | 64 | 57 | 7 | 5 | 2 |
| IEEEXplore | 5 | 5 | 0 | 0 | 0 |
| ScienceDirect | 8 | 7 | 1 | 0 | 1 |
| DOAJ | 2 | 2 | 0 | 0 | 0 |
| *Total* | *202* | *179* | *23* | *7* | *16* |

with children under 8 years. From the remaining 23 articles, 7 were duplicates, thus, 16 unique articles were analyzed.

### *7.2.2 Measurements*

In our review we wanted to explore: (a) the systems used in STEM research for children under 8 years old, (b) the intended intervention objectives and whether they were achieved, (c) the sample characteristics (students' age, sample size, level of education), (d) the group size, (e) the duration of the experiment, (f) the nature of the activities in which the students participated, (g) which user interface was used (GUI or TUI), (h) the accumulated data type and data source, and (i) the study design.

For this reason, we categorized some characteristics of the studies. Particularly, the intervention objectives refer to the cognitive area, to skills and attitudes that the participants can acquire after the intervention. The study subject refers to the content to be taught, which can be: (a) mathematics, (b) computer science, (c) robotics (combination of computer science with engineering), or (d) bioengineering (biological engineering). The activities refer to the tasks that the participants are asked to complete, which can be: (a) programming (e.g. navigate a robot up to path), (b) engineering (e.g. building robots to solve problems), or (c) mathematics. The data type can be qualitative, quantitative, or a combination of the two. Quantitative data obtained through written evaluations, are data about numeric variables and may show how many, or how often. While qualitative data obtained through observation and interviews, are data about categorical variables and may show types or behaviors. Data sources report how data were recorded, such as through questionnaires, observations, interviews, or videos.

Moreover, the study design according to Campbell and Stanley (1984) can be categorized into:

(a) Non-experimental, in which all students participate in the same activities (e.g. Cervera et al., 2020). If an intervention contains only a test (or observation) after the treatment, the design is called "One-Shot Case Study", otherwise it is called "One-Group Pretest–Posttest".
(b) True experimental, in which children are randomly divided into two groups. The experimental group participated in the program, while the control group used it as a reference. If an intervention contains only a test (or observation) after the treatment, the design is called "Posttest-Only Control Group", otherwise it is called "Pretest–Posttest Control Group".

Finally, it is recorded as a gain if the students reached the intervention objectives and had better results after participating in the program.

## 7.3 Findings

From the systematic literature review, various elements of STEM education in early childhood research were recorded. For better comparison and drawing conclusions, the findings are organized and categorized in tables. More specifically, Table 7.3 contains general characteristics and experimental information for each study. Thus,

**Table 7.3** General characteristics and experimental information

| | Study | Country | Intervention objectives[a] | Subjects | Activities[b] | Duration (min) |
|---|---|---|---|---|---|---|
| 1 | Cervera et al. (2020) | Spain | S and A | Computer science | P | 90 |
| 2 | Zviel-Girshin et al. (2020) | Israel | A | Robotics | E, P | ns |
| 3 | Sullivan and Bers (2018) | Singapore | K and S | Robotics | E, P | 420 |
| 4 | Strawhacker et al. (2020) | USA | A | Bioengineering | E, P | 540 |
| 5 | Sullivan and Bers (2016) | USA | K and S | Robotics | E, P | 480 |
| 6 | Jung et al. (2020) | USA | K | Robotics | E, P | 315 |
| 7 | Cho et al. (2017) | USA | S | Robotics | E, P | 315 |
| 8 | Metin (2020) | Turkey | K | Computer science | P | 600 |
| 9 | Master et al. (2017) | USA | A | Computer science | P | 20 |
| 10 | Baek et al. (2019) | USA | S | Robotics | E, P | 480 |
| 11 | Moore et al. (2020) | USA | K | Computer science | P | 240 |
| 12 | Sullivan and Bers (2019) | USA | A | Robotics | E, P | 420 |
| 13 | Taylor (2018) | USA | K | Computer science | P | ns |
| 14 | Sung et al. (2017) | USA | K | Mathematics | P, M | 300 |
| 15 | Taylor et al. (2017) | USA | K | Computer science | P | ns |
| 16 | Sullivan and Bers (2013) | USA | K | Robotics | E, P | 1080 |

[a] *K* knowledge, *S* skills, *A* attitudes
[b] *P* programming, *E* engineering, *M* mathematics

the table shows the names of the authors and the country in which the research was conducted. Also, the intervention objectives, the subject of the research, the nature of the activities that the students had to be involved in, and finally the duration of the studies are recorded.

We can conclude that the intervention objective in seven cases targeted knowledge, in four cases on attitudes, and in two cases on skills. In three cases there was a combination of knowledge, skills, and attitude. This shows that researchers are mainly interested in examining the level of knowledge, and less the skills and attitudes that participants acquire during the intervention.

Furthermore, robotics was the subject of research in eight cases, six cases had computer science as the research subject, while mathematics and bioengineering were the subjects of one research. This shows that robotics along with a combination of computer science and engineering, are the most popular subjects in STEM education in early childhood, while cognitive domains such as mathematics are less probable to be utilized. At the same time, it seems that the research and use of STEM technologies in other fields of knowledge such as language and history are extremely rare.

In nine cases the activities included programming and engineering tasks. Six cases included only programming activities, while in one case programming and mathematics was included. Additionally, as shown in Fig. 7.1, the duration of the research in seven cases was about 480 min.

Also, in only one case it was over 1000 min. This demonstrates that there is a shortage of long-term studies.

Table 7.4 lists the sample characteristics of the related studies. The school level (kindergarten or/and primary school), the age of the students, the number of the sample, the number of participants within a group, and the previous experience in STEM education are recorded. As shown in Fig. 7.2, only three studies (18.75%) were conducted exclusively in kindergarten, while six studies (37.5%) were mixed as they were conducted in primary schools and kindergartens simultaneously. Seven

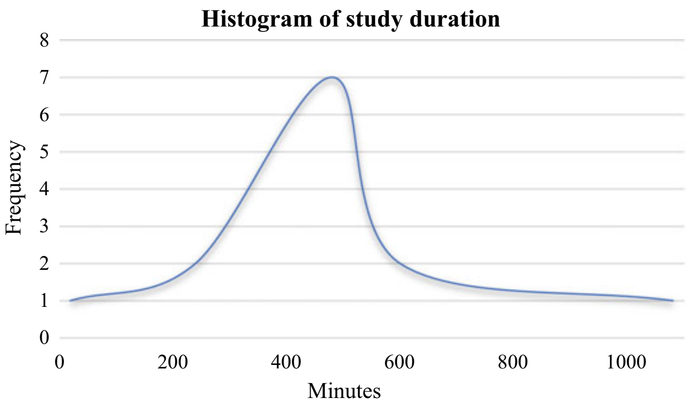


**Fig. 7.1** Study duration histogram

**Table 7.4** Sample characteristics

| Study | School(s)[a] | Age | Sample | Size of groups | Prior experience |
|---|---|---|---|---|---|
| 1 | P | 7–8 | 33 | 2–3 | Yes |
| 2 | K and P | 4–7 | 197 | 2–4 | No |
| 3 | K | 3–6 | 98 | ns | No |
| 4 | K and P | 4–7 | 25 | ns | No |
| 5 | K and P | 4–7 | 60 | 2–3 | ns |
| 6 | P | 8 | 1 | ns | No |
| 7 | P | 7–8 | 24 | 4 | ns |
| 8 | K | 5 | 24 | 2–5 | No |
| 9 | P | 6–7 | 96 | Individual | ns |
| 10 | P | 7–8 | 22 | 5 | Yes |
| 11 | P | 7–8 | 3 | 2 | No |
| 12 | K and P | 5–7 | 105 | ns | ns |
| 13 | K and P | 4–7 | 3 | Individual | ns |
| 14 | K and P | 5–7 | 66 | Individual | No |
| 15 | P | 6–8 | 3 | Individual | No |
| 16 | K | 5–6 | 53 | 4 | ns |

[a] *K* kindergarten, *P* primary school

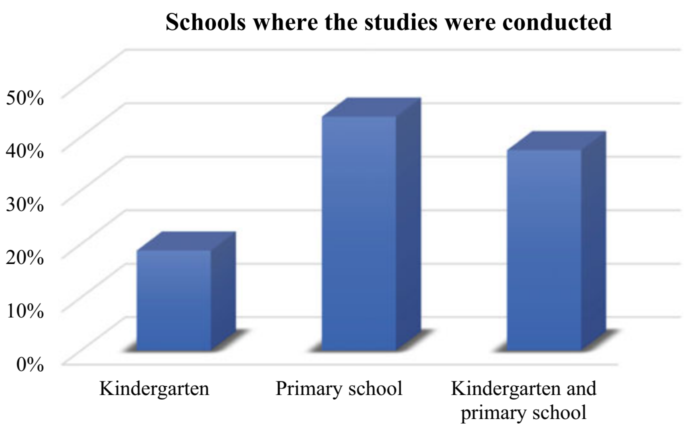


**Fig. 7.2** Studies in schools

studies (43.75%) were conducted exclusively in primary schools. So, it seems that there is a preference to involve children over 6 years old.

Also, as shown in Fig. 7.3, in four studies (25%) the number of children who participated was less than 10, while five studies (31.25%) had a sample of 10 to 40

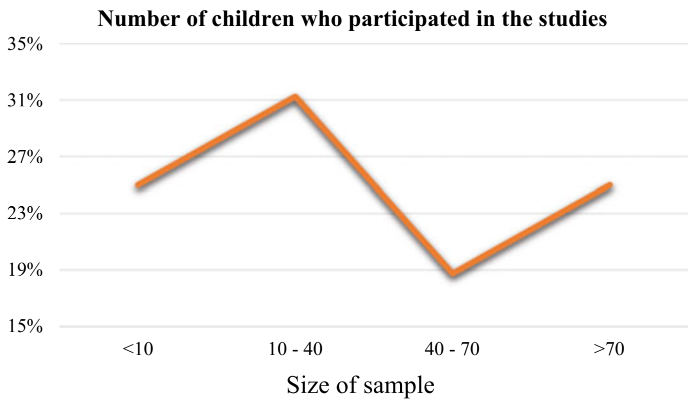


**Fig. 7.3** Sample size

children. Three studies (18.75%) had a sample of 40–70 children. Moreover, four studies (25%) had a sample of above 70 children.

In addition, as shown in Fig. 7.4, groups of 2 children were created in five cases (31.25%). Groups of 3 and 4 children were created in four cases respectively (25%). Groups of 5 children were created in two cases (12.5%). Finally, in four cases (25%) there were individual activities. Thus, the researchers chose mostly group activities, rather than individual activities.

Table 7.5 shows the equipment used for the research and the user interface. For this, the type of equipment, the brand name of the system, and how the children programming their STEM system are recorded.

In nine cases the type of equipment was wheeled. In four cases it was modular, while in one case it was (a) wheeled and modular, (b) game board, (c) software.

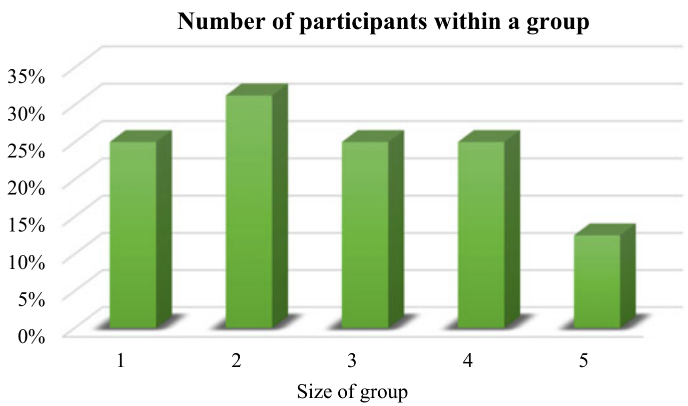


**Fig. 7.4** Group size

**Table 7.5** Equipment and user interface

| Study | Equipment type | Material object | User interface |
|---|---|---|---|
| 1 | Wheeled | Bee-Bot | Tangible |
| 2 | Modular | Lego robotics equipment | Graphical |
| 3 | Wheeled | KIBO | Tangible |
| 4 | Game Board | CRISPEE | Tangible |
| 5 | Wheeled | KIWI | Tangible |
| 6 | Modular | Cubelets | Tangible |
| 7 | Wheeled and Modular | Bee-Bots and Cubelets | Tangible |
| 8 | Wheeled | Cubetto | Tangible |
| 9 | Wheeled | Animal robot | Graphical |
| 10 | Modular | Mindstorms EV3 | Graphical |
| 11 | Wheeled | Code and Go™ Robo mouse activity set | Tangible |
| 12 | Wheeled | KIBO | Tangible |
| 13 | Wheeled | Dash | Graphical |
| 14 | Software | Scratch Jr | Graphical |
| 15 | Wheeled | Dash | Graphical |
| 16 | Modular | Lego Mindstorms | Tangible and graphical |

[a] *P* programming, *E* engineering, *M* mathematics

Regarding the STEM system, in three cases Lego equipment was used, while in two cases: Bee-Bot, KIBO, Cubelets, and Dash. In all the other cases there was a system which was used only once. This reveals the dynamics of wheeled robotic systems and a preference for Lego equipment for early childhood.

In addition, as shown in Fig. 7.5, STEM systems were programmed, in nine cases with TUI, and in six cases with block-based GUI. Finally, in one case a TUI-GUI combination was used.

Table 7.6 records the design of each research, the type of data extracted by the researchers, the data source, and the results of the studies.

Nine designs were "One-Shot Case Study" (see Fig. 7.6a). Four designs were "One-Group Pretest–Posttest", while "Posttest-Only Control Group" design was used once. Lastly, two studies were "Pretest–Posttest Control Group". It is worth mentioning that the design is non-experimental in thirteen cases, while in only three cases it is true experimental. Moreover, as shown in Fig. 7.6b, accumulated data type was quantitative in six cases, while in five cases accumulated data type was qualitative. Similarly, accumulated data type was mixed in five cases.

For data source, as shown in Fig. 7.7, questionnaires were used in eleven cases (68.8%), interviews in six cases (37.5%), video in five cases (31.3%), and observation in four cases (25%). Finally, the vast majority of studies were beneficial for students and met the intervention objectives, while in one study no gain was observed.

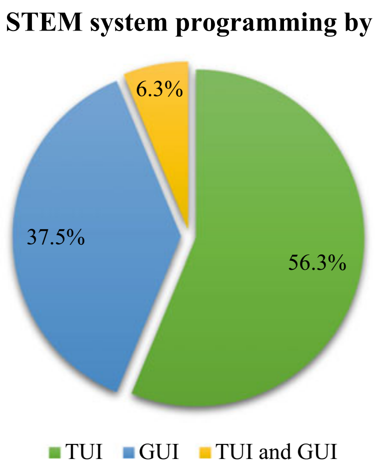


**Fig. 7.5** User interface

**Table 7.6** Design, data and results

| Study | Design type | Data type[b] | Data source[c] | Results |
|---|---|---|---|---|
| 1 | One-shot case study | Q and q | Qu, O | Gain |
| 2 | One-shot case study | Q and q | Qu, V, I | Gain |
| 3 | One-group pretest–posttest | Q and q | Qu, I | Gain |
| 4 | One-group pretest–posttest | Q and q | Qu, O | Gain |
| 5 | One-shot case study | Q | Qu | Gain |
| 6 | One-shot case study | q | V, I | Gain |
| 7 | One-shot case study | q | V, I | Gain |
| 8 | One-group pretest–posttest | Q | Qu | Gain |
| 9[a] | Posttest-only control group | Q | Qu | Gain |
| 10 | One-group pretest–posttest | Q and q | Qu, I | Gain |
| 11 | One-shot case study | q | V, I | Gain |
| 12[a] | Pretest–posttest control group | Q | Qu | Gain |
| 13 | One-shot case study | q | O | Gain |
| 14[a] | Pretest–posttest control group | Q | Qu | Gain |
| 15 | One-shot case study | q | V, O | Gain |
| 16 | One-shot case study | Q | Qu | No Gain |

[a]Experimental study design
[b]*Q* quantitative, *q* qualitative
[c]*Qu* questionnaire, *O* observation, *V* video, *I* interview

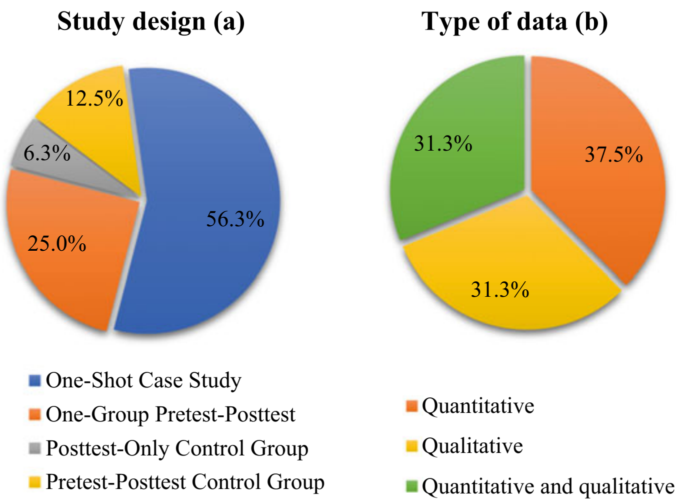


**Fig. 7.6** **a** Study design, and **b** Data type

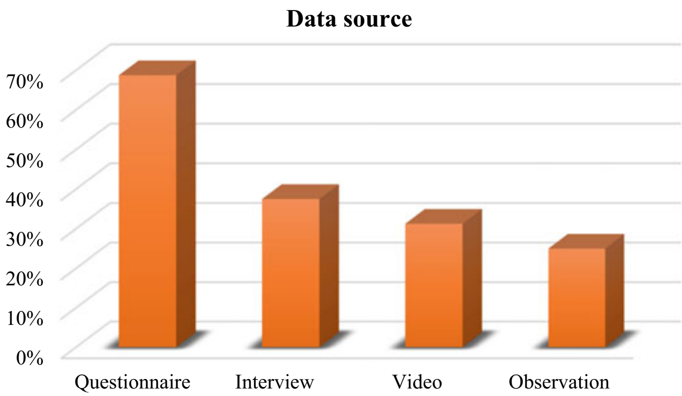


**Fig. 7.7** Data source

## 7.4 Discussion

According to the findings, the majority of studies were conducted in the USA. This is in accordance with the findings made by Ata Aktürk and Demircan (2017) and Wan et al. (2020) about STEM education in early childhood. This might not be a coincidence, as in 2007 the United States invested $ 3 billion in STEM education programs (Kuenzi, 2008), showing a strong willingness to engage in this field ever since.

Half of the studies were conducted exclusively in primary school, while in thirteen cases 7-year-old children participated or older. This can be related to the intellectual developmental stages of Piaget, as from the age of 7, the children enter in Concrete Operational stage (Ripple & Rockcastle, 1964). At this stage, children begin to think more logically and efficient, and these elements are needed for STEM education.

According to researchers organizing, managing, and executing a study with young students may have difficulties and practical problems. Perhaps for these reasons "One-Shot Case Study" is more preferable. This study design might be considered as simpler and more practical since it has no group separation or pretest implementation. However, the research, in this case, might be weak and the results cannot be easily generalized.

It is noteworthy that in twelve studies (75%) the number of children who participated was less than 70. We must not overlook the fact that the sample size gives depth and quality to the research's findings. Likewise, the duration of the intervention raises reliability questions for the findings, as only one study lasted more than 10 h.

Moreover, according to Bloom's Taxonomy, the learning objectives can be categorized into three domains: cognitive, affective, and psychomotor (Bloom, 1956). Consequently, in the educational process students develop knowledge, emotions/attitudes, and skills. Nevertheless, intervention objectives in almost half of the cases targeted on knowledge. That is, the educational/research community remains focused on cognition, ignoring the other domains.

In four cases the researchers chose individual activities for students, avoiding the benefits of collaborative learning. Thus, these participants did not, inter alia, benefit psychologically, socially, or academically (Laal & Ghodsi, 2012).

More than half of the activities were a combination of programming and engineering, so, the activities were interdisciplinary. This is in agreement with the findings made by Ata Aktürk and Demircan (2017). Likewise, half of the research focused on robotics. STEM education in early childhood seems to emphasize on robotics and is not used as a learning tool for other subjects like history.

Regarding the equipment type, wheeled robotic systems were used in more than half cases, while Lego equipment was mostly used, followed by Bee-Bot, KIBO, Cubelets, and Dash. We can observe that commercial systems were used and not new research tools. In fact, these are not open systems, although open technologies are popular (Sapounidis & Alimisis, 2021).

Also, in more than half of the cases, the robotic system was programmed with TUI. This finding agrees with Sapounidis et al. (2019a, 2019b), as children seem to prefer this interface, showing a more positive attitude.

In addition, none of the articles we included in our review are earlier than 2013. This agrees with Wan et al. (2020), and may be an indication that STEM education has been integrated into early childhood in recent years.

Finally, only in one case, there was no gain in the results. However, it should be noted that the sample of 16 articles may not be sufficient to draw safe conclusions. As future research we propose to cover the literature review with more searches/keywords in more databases. In addition, it would be interesting to include not only studies involving students, but also studies about the attitudes of teachers and parents around STEM education.

## 7.5 Conclusion

In the past, several reviews investigated STEM effects in learning, indicating that students develop digital and soft skills. However, they did not examine the effects in early childhood. Thus, this review focused on STEM research for students under 8 years old. Moreover, the article provides a lot of useful information about the implementation of the studies and the findings that emerge.

Summarizing the results, the majority of robotic systems are wheeled and are programmed with TUIs. The groups consist mainly of 2–4 members, and students over the age of 6 are preferred. The duration of the experiment usually does not exceed 10 h, while the activities are a combination of programming and engineering. Lastly, most often the "One-Shot Case Study" design is used.

Despite the possible weaknesses, along with the absence of long-term studies, and lack of quantitative methods, STEM education in early childhood seems to successfully meet the intervention objectives.

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**Data Availability Statement** The data presented in this study are available on request from the corresponding author.

**Author Contributions** S. T. and T. S. conceived, designed, and wrote together this paper. All authors have read and agreed to the published version of the manuscript.

## References

Angeli, C., & Valanides, N. (2020). Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy. *Computers in Human Behavior, 105*, 105954. https://doi.org/10.1016/j.chb.2019.03.018

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research, 9*(2), 19–42. https://doi.org/10.7771/2157-9288.1223

Arfé, B., Vardanega, T., & Ronconi, L. (2020). The effects of coding on children's planning and inhibition skills. *Computers and Education*, *148*(May 2019). https://doi.org/10.1016/j.compedu.2020.103807

Ata Aktürk, A., & Demircan, O. (2017). A review of studies on STEM and STEAM education in early childhood. *Journal of Kırşehir Education Faculty, 18*(2), 757–776.

Baek, Y., Wang, S., Yang, D., Ching, Y.-H., Swanson, S., & Chittoori, B. (2019). Revisiting second graders' robotics with an understand/use-modify-create ($U^2$MC) strategy. *European Journal of STEM Education*, *4*(1), 1–12. https://doi.org/10.20897/ejsteme/5772

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers and Education, 58*(3), 978–988. https://doi.org/10.1016/j.compedu.2011.10.006

Bloom, B. S. (1956). *Taxonomy of educational objectives. Vol. 1: Cognitive domain* (pp. 20, 24). McKay.

Campbell, D. T., & Stanley, J. C. (1984). Experimental and quasi-experiment Al designs for research. In *Contemporary Psychology: A Journal of Reviews, 29*(4). https://doi.org/10.1037/022808

Cervera, N., Diago, P. D., Orcos, L., & Yáñez, D. F. (2020). The acquisition of computational thinking through mentoring: An exploratory study. *Education Sciences, 10*(8), 1–11. https://doi.org/10.3390/educsci10080202

Çetin, M., & Demircan, H. Ö. (2020). Empowering technology and engineering for STEM education through programming robots: A systematic literature review. *Early Child Development and Care, 190*(9), 1323–1335. https://doi.org/10.1080/03004430.2018.1534844

Chapman, A., Rodriguez, F. D., Pena, C., Hinojosa, E., Morales, L., Del Bosque, V., Tijerina, Y., & Tarawneh, C. (2020). "Nothing is impossible": Characteristics of Hispanic females participating in an informal STEM setting. *Cultural Studies of Science Education, 15*(3), 723–737. https://doi.org/10.1007/s11422-019-09947-6

Chevalier, M., Giang, C., Piatti, A., & Mondada, F. (2020). Fostering computational thinking through educational robotics: a model for creative computational problem solving. *International Journal of STEM Education*, *7*(1). https://doi.org/10.1186/s40594-020-00238-z

Chiazzese, G., Arrigo, M., Chifari, A., Lonati, V., & Tosto, C. (2019). Educational robotics in primary school: Measuring the development of computational thinking skills with the bebras tasks. *Informatics*, *6*(4). https://doi.org/10.3390/informatics6040043

Ching, Y. H., Yang, D., Wang, S., Baek, Y., Swanson, S., & Chittoori, B. (2019). Elementary school student development of STEM attitudes and perceived learning in a STEM integrated robotics curriculum. *TechTrends, 63*(5), 590–601. https://doi.org/10.1007/s11528-019-00388-0

Cho, E., Lee, K., Cherniak, S., & Jung, S. E. (2017). Heterogeneous associations of second-graders' learning in robotics class. *Technology, Knowledge and Learning, 22*(3), 465–483. https://doi.org/10.1007/s10758-017-9322-3

Cutumisu, M., Adams, C., & Lu, C. (2019). A scoping review of empirical research on recent computational thinking assessments. *Journal of Science Education and Technology, 28*(6), 651–676. https://doi.org/10.1007/s10956-019-09799-3

Demetriadis, S., Giannouli, V., & Sapounidis, T. (2015). Robot programming and tangible interfaces for cognitive training. In *Handbook of research on innovations in the diagnosis and treatment of dementia*. https://doi.org/10.4018/978-1-4666-8234-4.ch011

Gao, X., Li, P., Shen, J., & Sun, H. (2020). Reviewing assessment of student learning in interdisciplinary STEM education. *International Journal of STEM Education*, *7*(1). https://doi.org/10.1186/s40594-020-00225-4

Ioannou, A., & Makridou, E. (2018). Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work. *Education and Information Technologies, 23*(6), 2531–2544. https://doi.org/10.1007/s10639-018-9729-z

Ioannou, M., & Ioannou, A. (2020). Technology-enhanced embodied learning: Designing and evaluating a new classroom experience. *Educational Technology and Society, 23*(3), 81–94.

Johnson, J. (2003). Children, robotics, and education. *Artificial Life and Robotics, 7*(1–2), 16–21. https://doi.org/10.1007/bf02480880

Julià, C., & Antolí, J. Ò. (2016). Spatial ability learning through educational robotics. *International Journal of Technology and Design Education, 26*(2), 185–203. https://doi.org/10.1007/s10798-015-9307-2

Jung, S. E., Lee, K., Cherniak, S., & Cho, E. (2020). Non-sequential learning in a robotics class: insights from the engagement of a child with autism spectrum disorder. *Technology, Knowledge and Learning, 25*(1), 63–81. https://doi.org/10.1007/s10758-018-9394-8

Konijn, E. A., & Hoorn, J. F. (2020). Robot tutor and pupils' educational ability: Teaching the times tables. *Computers and Education*, *157*(December 2019), 103970. https://doi.org/10.1016/j.compedu.2020.103970

Kuenzi, J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action*. https://digitalcommons.unl.edu/crsdocs/35/

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia—Social and Behavioral Sciences, 31*(2011), 486–490. https://doi.org/10.1016/j.sbspro.2011.12.091

Li, Y., Schoenfeld, A. H., diSessa, A. A., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2020). Computational thinking is more about thinking than computing. *Journal for STEM Education Research, 3*(1), 1–18. https://doi.org/10.1007/s41979-020-00030-2

Master, A., Cheryan, S., Moscatelli, A., & Meltzoff, A. N. (2017). Programming experience promotes higher STEM motivation among first-grade girls. *Journal of Experimental Child Psychology, 160*, 92–106. https://doi.org/10.1016/j.jecp.2017.03.013

Metin, S. (2020). Activity-based unplugged coding during the preschool period. *International Journal of Technology and Design Education*, *0123456789*. https://doi.org/10.1007/s10798-020-09616-8

Moore, T. J., Brophy, S. P., Tank, K. M., Lopez, R. D., Johnston, A. C., Hynes, M. M., & Gajdzik, E. (2020). Multiple representations in computational thinking tasks: A clinical study of second-grade students. *Journal of Science Education and Technology, 29*(1), 19–34. https://doi.org/10.1007/s10956-020-09812-0

Muñoz, L., Villarreal, V., Morales, I., Gonzalez, J., & Nielsen, M. (2020). Developing an interactive environment through the teaching of mathematics with small robots. *Sensors (Switzerland), 20*(7), 1–23. https://doi.org/10.3390/s20071935

Nemiro, J. E. (2020). Building collaboration skills in 4th- to 6th-grade students through robotics. *Journal of Research in Childhood Education, 00*(00), 1–22. https://doi.org/10.1080/02568543.2020.1721621

Newton, K. J., Leonard, J., Buss, A., Wright, C. G., & Barnes-Johnson, J. (2020). Informal STEM: Learning with robotics and game design in an urban context. *Journal of Research on Technology in Education, 52*(2), 129–147. https://doi.org/10.1080/15391523.2020.1713263

Ripple, R. E., & Rockcastle, V. N. (1964, March). *Piaget rediscovered. A report of the conference on cognitive studies and curriculum development.*

Sapounidis, T., & Alimisis, D. (2020). Educational robotics for STEM: A review of technologies and some educational considerations. In *Science and mathematics education for 21st century citizens: Challenges and ways forward* (pp. 167–190).

Sapounidis, T, & Alimisis, D. (2021). *Educational Robotics Curricula: Current Trends and Shortcomings* (pp. 127–138). Springer. https://doi.org/10.1007/978-3-030-77022-8_12

Sapounidis, T., Stamelos, I., & Demetriadis, S. (2016). Tangible user interfaces for programming and education: A new field for innovation and entrepreneurship. *Advances in Digital Education and Lifelong Learning, 2*, 271–295. https://doi.org/10.1108/S2051-229520160000002016

Sapounidis, T., Demetriadis, S., Papadopoulos, P. M., & Stamovlasis, D. (2019a). Tangible and graphical programming with experienced children: A mixed methods analysis. *International Journal of Child-Computer Interaction, 19*, 67–78. https://doi.org/10.1016/j.ijcci.2018.12.001

Sapounidis, T., Stamovlasis, D., & Demetriadis, S. (2019b). Latent class modeling of children's preference profiles on tangible and graphical robot programming. *IEEE Transactions on Education, 62*(2), 127–133. https://doi.org/10.1109/TE.2018.2876363

Sisman, B., Kucuk, S., & Yaman, Y. (2020). The effects of robotics training on children's spatial ability and attitude toward STEM. *International Journal of Social Robotics*. https://doi.org/10.1007/s12369-020-00646-9

Strawhacker, A., Verish, C., Shaer, O., & Bers, M. (2020). Young children's learning of bioengineering with CRISPEE: A developmentally appropriate tangible user interface. *Journal of Science Education and Technology, 29*(3), 319–339. https://doi.org/10.1007/s10956-020-09817-9

Sullivan, A., & Bers, M. U. (2013). Gender differences in kindergarteners' robotics and programming achievement. *International Journal of Technology and Design Education, 23*(3), 691–702. https://doi.org/10.1007/s10798-012-9210-z

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International*

*Journal of Technology and Design Education, 26*(1), 3–20. https://doi.org/10.1007/s10798-015-9304-5

Sullivan, A., & Bers, M. U. (2018). Dancing robots: Integrating art, music, and robotics in Singapore's early childhood centers. *International Journal of Technology and Design Education, 28*(2), 325–346. https://doi.org/10.1007/s10798-017-9397-0

Sullivan, A., & Bers, M. U. (2019). Investigating the use of robotics to increase girls' interest in engineering during early elementary school. *International Journal of Technology and Design Education, 29*(5), 1033–1051. https://doi.org/10.1007/s10798-018-9483-y

Sung, W., Ahn, J., & Black, J. B. (2017). Introducing computational thinking to young learners: Practicing computational perspectives through embodiment in mathematics education. *Technology, Knowledge and Learning, 22*(3), 443–463. https://doi.org/10.1007/s10758-017-9328-x

Taylor, M. S. (2018). Computer programming with pre-K through first-grade students with intellectual disabilities. *Journal of Special Education, 52*(2), 78–88. https://doi.org/10.1177/0022466918761120

Taylor, M. S., Vasquez, E., & Donehower, C. (2017). Computer programming with early elementary students with down syndrome. *Journal of Special Education Technology, 32*(3), 149–159. https://doi.org/10.1177/0162643417704439

Tlili, A., Lin, V., Chen, N. S., Huang, R., & Kinshuk. (2020). A systematic review on robot-assisted special education from the activity theory perspective. *Educational Technology and Society*, *23*(3), 95–109.

Tselegkaridis, S., & Sapounidis, T. (2021). Simulators in educational robotics: A review. *Education Sciences, 11*(1), 1–12. https://doi.org/10.3390/educsci11010011

Wan, Z. H., Jiang, Y., & Zhan, Y. (2020). STEM education in early childhood: A review of empirical studies. *Early Education and Development, 00*(00), 1–23. https://doi.org/10.1080/10409289.2020.1814986

Xia, L., & Zhong, B. (2018). A systematic review on teaching and learning robotics content knowledge in K–12. *Computers and Education, 127*, 267–282. https://doi.org/10.1016/j.compedu.2018.09.007

Zviel-Girshin, R., Luria, A., & Shaham, C. (2020). Robotics as a tool to enhance technological thinking in early childhood. *Journal of Science Education and Technology, 29*(2), 294–302. https://doi.org/10.1007/s10956-020-09815-x

# Chapter 8
# Design Thinking and Digital Technologies in the Exploration of Science in Early Childhood Education

**Sofia Chatzigeorgiadou, Maria Hatzigianni, Fotini Ratkidou, and Soultana Toziou**

**Abstract** Contemporary early childhood research investigates ways of extending children's scientific understanding and knowing in the world around them. The current study followed an innovative approach, adopting the design thinking model of IDEO to promote and deepen children's scientific thinking and understanding of the 'water cycle'. Digital technologies such as concept map software, simulations, interactive whiteboard and others, were also successfully integrated and played a significant role in the whole process. A total of 61 children from three Greek kindergartens participated in the study (33 boys and 28 girls) and their mean age was 5.2 years. Teachers' diaries of the activities following the IDEO phases, digital recordings of children's responses, drawings and concept maps were utilised for the documentation of the teaching intervention. The results revealed that the IDEO model was very helpful and contributed to reaching positive learning outcomes. Children were active participants throughout the intervention and their scientific knowledge was enhanced. Future research with a design thinking framework in exploring science in early childhood education settings is strongly recommended by also successfully integrating digital tools.

**Keywords** Design thinking · Early childhood education · Science · Digital technologies · Kindergarten

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## 8.1 Introduction

The early years of life are fundamental as they greatly influence individuals' prospects concerning development, education, and employment. Modern early childhood curricula are designed to provide children with the necessary skills that 'citizens need for their personal integration, social inclusion, active citizenship and employment in our knowledge-based society' (Council of Europe, 2018).

In 2020, the Hellenic Ministry of Education (MoE) introduced and piloted a renewed skills model called 'Skills Laboratories' in the school curricula reform agenda. This model focuses on developing appropriate skills in children for twenty-first century life (MoE, 2020). The implementation of this agenda combines four categories of skills organized in cycles that each one promotes (a) learning skills, (b) life skills, (c) technology and science skills, and finally (d) mind skills, in compliance with the Global Sustainable Development Goal Indicators (IAEG-SDGs, 2017). In line with this reform, contemporary early childhood research investigates ways of extending and supporting children-n's scientific and holistic knowing and being in the world (Campbell & Jobling, 2021; Kalogiannakis et al., 2018). The vital role of early years is recognized and underlined in the development of the aforementioned skills (Care et al., 2018). When children are introduced to the scientific process early in their life, they have a higher chance of following a scientific career, gender stereotypes are eliminated and are better equipped for the uncertainty and complexity of their future careers (van Tuijl & van der Molen, 2016). Moreover, the integration of digital technologies is more widely accepted in the sector now (Hatzigianni & Kalaitzidis, 2018). A plethora of studies argue for the advances these new technologies can offer in teaching young children opportunities to exercise higher order thinking, creativity, innovation, and collaboration (Falloon, 2020; Giezma et al., 2013; Guha et al., 2004; Lai & Hwang, 2014; Loveless, 2002, 2008).

In the Greek early childhood (EC) curriculum (MoE, 2014), the planning of scientific explorations and the active involvement of young children with science and technology is underlined. Young children shape their basic ideas and interpretations of concepts and phenomena of the natural world and are therefore able to approach relevant issues at a first level in this age. Research confirms that the earliest years of elementary school (kindergarten and first grade) are critical for the development of science knowledge and skills (Curran & Kitchin, 2019; McClure et al., 2017).

The EC curriculum includes topics on nature, environmental issues and human activities in the unit 'Science' and emphasises the way children recognise, gather and construct knowledge on the world around them. One of the topics included is 'Meteorological phenomena' and a possible plan of aims along with proposed activities from this topic pertain to Science Teaching. The basic aims of the topic are (a) to distinguish the weather phenomena and the characteristics of meteorological observations (sun, clouds, rain, snow), (b) to select and use appropriate vocabulary (e.g., temperature, humidity, etc.) and symbols (e.g., the sun for sunny days, the raindrops for rain, etc.) to capture their relevant observations and (c) to recognise repeated patterns (e.g., warmer days in summertime) in the weather phenomena.

In this study we explored the 'Water cycle' as a means to process the multiple information for the analysis of the weather/meteorological phenomena in order to approach holistically the three aims.

The water cycle, a difficult, abstract concept, is popular among EC teachers and very often investigated by preschoolers. Water, as a dominant element of weather phenomena is an integral part of many children's stories and everyday play and deepens children's understanding of the natural world and of the environment around them (Papadopoulos & Seroglou, 2007). Following the EC curriculum this study focused on the exploration and understanding of the 'water cycle' and introduced children to the scientific process of asking questions, making hypotheses, testing hypotheses, experimenting, collecting data and evaluating their findings.

We followed a constructivistic theoretical framework which usually underpins science education, and its principles are identified and evaluated positively (Hendry, 1996). These principles can be applied successfully to classroom teaching and learning especially in early childhood education. Knowledge is not taught. New knowledge is constructed (Ausubel, 2000) between teacher and students through perception and action, in communicational circumstances (Roschelle & Clancey, 1992; Vygotsky, 1978b). Children have certain ideas and concepts that 'are sensible and useful from the child's point of view allowing reasonable interpretation, and successful prediction, of everyday experiences' (Osborne, 1982, p. 25). Thus, before the construction of new knowledge it is important to examine children's previous forms of knowledge which are qualitatively different and will aid them in the active integration of new ideas through exploration (Dejonckheere et al., 2016; Driver & Bell, 1986; Driver & Oldham, 1986).

Additionally, we adopted a new teaching approach, design thinking, and with the help of digital technologies we aimed at deepening children's scientific understanding and enhancing their critical and creative thinking, problem solving, innovation and collaboration.

## 8.2 Research Design

This study describes a two-months teaching intervention which lasted from January 2020 till March 2020, consisting of two-hours weekly activities. The main aim was to propose a teaching intervention in which teachers and children would explore the abstract concepts around the water cycle and its association with the weather phenomena (e.g., evaporation, liquefaction etc.) and finally children would be able to explain using their own designs and words the whole process. The project's cognitive goals can be summarised as follows: (a) to study the 'water cycle' as a natural phenomenon, (b) to review the three natural properties of water (liquid–solid-steam), and finally (c) to understand the factors that affect water. With the design thinking approach teachers supported children to investigate collaboratively their prior knowledge and their perceptions on the phenomenon by discussing, recording, mapping, and testing their views and beliefs. Design thinking was the learning framework of this teaching intervention and simultaneously operated as the research method that facilitated the collection of children's learning outcomes (concept maps, recordings of group conversations, photos, and drawings). The intervention was contacted in accordance with the five phases of IDEO model and teachers kept systematic diaries of the activities and children's achievements.

### 8.2.1 Participants

Convenience sampling was used in this study. This type of sampling does not allow for generalisations but ensures efficiency of data collection, and is suitable for projects with no funding (Cohen et al., 2017). Three kindergarten teachers (mean age 54 years), with over 20 years of teaching experience and sufficient digital competence from three kindergartens in Thessaloniki, Greece's second larger city, were actively involved in the study. The three kindergartens were selected because they were taking part in the pilot implementation of the MoE's new curriculum agenda 'Skills Laboratories', and they were fully equipped with the appropriate digital technologies (interactive boards, computers etc.). A total of 61 children participated in the study (33 boys and 28 girls) and their mean age was 5.2 years (SD = 0.78).

### 8.2.2 Methods and the Design Thinking Approach

The research methods included teachers' diaries and children's documentation of achievements, such as concept maps and drawings that provided the assessment of learning outcomes. These methods will be presented and further explained in the following sections under each design thinking phase. The following presentation is a summary of the teachers' diaries and outlines an insight of the teaching intervention. This paper will address the following research questions:

1. In what ways can the design thinking approach enhance young children's understanding about the water cycle?
2. How can we use digital technologies to enhance children's scientific understanding?

Studies on the design thinking process for young children are rapidly emerging and have also established connections between design thinking skills, and creative and critical thinking skills (Grammenos, 2016; Shively, et al., 2018; Yalçın & Erden, 2021) arguing for the importance of those skills for future generations. Recent studies have investigated the effect of using a design thinking teaching method on primary and secondary school students' achievement in physics concepts in the context of STEM learning. They documented a positive impact on student's construction of knowledge through discovery (Dotson et al., 2020; Kavousi et al., 2019; Simeon et al., 2020; Strimel et al. 2020; Wind et al., 2019). However, studies on young children's design thinking and its influence especially in science education are still extremely limited.

Design thinking is a discipline that uses the designer's mindset and methods through human centered techniques to engage children in the changing learning environment (Fierst et al., 2011). It is a non-linear protocol abductive in nature as it requires to create new ideas leading to creative solutions and addressing real teaching problems (Kimbell, 2016; Siang, 2017). Recent research has revealed that design thinking provides 'a natural bridge between subjects… focusing on the integration of computational thinking and computational making approaches within STEM education environment' (Juškevičienė et al., 2021, p. 210).

In the present study, the IDEO model was adopted for the exploration of the 'water cycle' and was used as a basic frame for the organised learning activities and their documentation. Among the available models, the IDEO model (Fierst et al., 2011) is particularly helpful in providing teachers with a detailed free handbook that includes scaffolds, stimulus, first-hand accounts and expert advice. It is characterised by the four following elements: (a) it is human-centered, (b) it is collaborative, (c) it is optimistic, and (d) it is experimental (Fierst et al., 2011). It encompasses five phases: (a) discovery, (b) interpretation, (c) ideation, (d) experimentation and (f) evolution.

### *8.2.3 Ethics*

The study received ethical approval by the committee of Early Childhood Education of Aristotle University of Thessaloniki. The early childhood coordinator was also informed about the purpose and the methodology of the study. A scheduled school—family meeting was organised and during that meeting all relevant consent forms were completed by parents. Finally, children were informed about the purpose and the content of the study. All children names that appear in this paper are pseudonyms to maintain anonymity, confidentiality, and privacy.

### *8.2.4 Analysis*

Teachers' diaries, children's comments and achievement through their drawings and concept maps were all collected and discussed between the researchers and the teachers. Emerging themes were summarised and organised under each scientific topic and IDEO phase. Results are presented below under each IDEO section.

## 8.3 Discovery

In this first phase, the prior knowledge and representations of the children were detected and all the preparations for the project were made. The weather change with the heavy rains in early December aroused children's interest and questions around weather. During this phase, teachers presented the story 'The cloud that cried' by Mantouvalos (2012) in the interactive whiteboard. After the story telling, a discussion aimed at exploring the perceptions of children about the phenomenon of the water cycle. The teachers asked questions such as: 'Where do you think the water comes from?', 'How is rain created?' How is the snow created?', and 'What are the clouds made of?'.

According to prior research, children were expected to have three relevant misconceptions about the water cycle: (a) they do not associate clouds with rain, as they largely believe that rain comes from the sky and not from the clouds, because rain is liquid while the clouds are in solid form (Bar, 1989; Christidou & Hatzinikita, 2005; Miner, 1992), (b) according to Bar and Galili (1994) young children (before the age of 7) believe that water disappears during the evaporation stage, (c) children do not link the change in the physical state of water with the exchange of heat between water and the environment (as reported in Christidou et al., 2003). Moreover, Ben-zvi-Assarf and Orion (2005) found that even older children have many misconceptions about the stages of water cycle occurring in the atmosphere. For example, more recent studies have reported that children may have general knowledge about rain, they experience difficulties in understanding the formation of rain and the concepts related to the water cycle, such as evaporation and condensation (Ahi, 2017; Saçkes et al., 2010; Savva, 2014; Strang & Aberg-Bengtsson, 2010). Even older children (eight and nine years old) experience difficulties in understanding some aspects of the phenomenon that occur in the atmosphere and the changes of water states (Vo et al., 2015).

Teachers encouraged all children to express as many views as possible. Children's statements and all the different answers were recorded and were presented visually on the interactive whiteboard in the form of a concept map with the central phrase 'What do I know about water?'. Coggle software was used, and children had the opportunity to interact with the software during the creation of the concept map. Teachers encouraged children to express their views by explaining that: 'We are making a map of what we know about water'. Children were enthusiastic and provided many different ideas about water, rain, clouds, and snow. For example, Kostas said, 'rain drops from the sky…' and Maria persisted that 'the clouds are made of cotton'.

Children mentioned that water comes from the sea, the rivers, the lakes, the sky, and finally the water taps. None of them could answer the question how rain is created and all of them persisted that it just drops from the sky, or the sun and a small number of them mentioned that it is an act of God. A few children argued that snow is soft like cotton and all of them agreed that snow is basically ice. They all were aware that ice is frozen water, and all of them had touched snow and ice, or ice cubes. Most of them knew that snow melts to water, and that water boils when it is heated. However, none assumed what happens to steam afterwards. They supposed that steam disappears in the air. All of them supposed that the drops of water from the sea, or lakes disappear in the air during the summer and whenever the temperature rises. These findings were consistent with previous research and the three misconceptions of the water cycle that were mentioned above.

The recorded ideas that supported the understanding of children's prior knowledge provided the necessary initial information for the teachers to plan the next step. A deeper scientific understanding and learning enhancement of all the prior alternative perceptions that children carried was needed. The aim to deepen their scientific understanding and enhance their knowledge guided the second phase of the project the phase of 'Interpretation'.

## 8.4 Interpretation

During interpretation learning occurs mostly through conversations and the recollection of observations. Ideas are generated during the learning management of the diverse alternative perceptions that children expressed in the previous phase. Group findings from field research and experiments were categorised into different themes and provided the basis for the learning enhancement of each alternative perception which the children expressed. Children watched multimedia applications (simulations and animations) that presented a macroscopic description of the phenomenon (evaporation-clouds-rain or snow) and deepened the discussion about the physical condition of water.

(a) The first alternative perception concerned the physical condition of water and its natural changes. Children watched the multimedia application 'The water cycle' from the USA Environmental Protection Agency (epa.gov) on the interactive whiteboard to stimulate discussion. During the presentation, the sound was turned off and the teachers translated the contend. Children were given the opportunity to decide whether to stop the video and/or to continue it during the discussion.

The key questions used for the reconstruction of the alternative prior perceptions were the following:

- Where does the rain come from?
- What are clouds made of?
- How is rain created in the clouds?

Prior to the closure of the activity, children were shown animated videos of the natural water circle by 'Photodentro' an Educational platform of the Greek MoE, and from NASA.

These animations facilitated deeper discussion around the physical state of water in regard to the next two alternative perceptions.

(b) The second and the third alternative perception concerned the natural state of water (gas–liquid-solid) and its changes. The key questions for their reconstruction were the following:

Have you ever seen water change color or shape? Do you know why and when:

1. water converts to gas?
2. water converts from gas to liquid?
3. water converts from liquid to solid.
4. water converts from solid to liquid.

Children experimented with the simulation ‘The phenomenon of evaporation’. The aim was to process the evaporation of water and its dependence on the changes of different factors such as temperature, wind, and humidity.

Overall, during this phase, children were able to associate clouds with rain as they observed in the videos and discussed with teachers that rain comes from the clouds. Their experimentation with the digital simulation managed to link the change in the physical state of water with the exchange of heat between water and the environment. This parameter was important for deepening their scientific understanding of the change in the physical states of water and finally to comprehend that water does not disappear during the evaporation stage. By the end of this phase children possessed a better understanding of the process of the water cycle. This understanding would be further enhanced in the next phase of Ideation.

## 8.5 Ideation

During this phase, children are encouraged to think expansively and without constraints. This phase needs a careful preparation and a clear set of rules, while its aim is to yield fresh ideas. An important element for its success is the selection of an appropriate room or a room with sufficient space. The participants should comfortably get up from their chairs and move around. At this point, a quick brainstorming of new ideas took place.

Teachers used open-ended questions with the purpose to inspire the ideation on the phenomenon. Some of the questions were: Why does water evaporate? What happens to the rain? How could we see the changes of water? How could we make rain or steam? Could we make snow or ice? Do you know the shape of snowflakes? Have you ever seen snowflakes up close? How could we represent the water cycle? What materials should we use?

Children imagined ways to experiment with the different properties of water in the classroom and with everyday materials or materials that they could find in school. The answers to the open questions were quite interesting, for example, they mentioned the use of boiling water for the creation of steam, the preparation of ice cubes in the fridge and others. Children also expressed their desire to see snow. The visual representation of crystals of snow were found in web search so as to understand the change of the natural state of water. Children found photos of snow crystals and retrieved them with their teachers' aid. As a result, they understood: (a) the change of the natural state of water from liquid to solid and (b) the contribution of low temperature.

In this phase children expressed different ideas for the examination of the phenomenon, initiated a range of activities and their scientific understanding was further enhanced.

In the next phase of 'experimentation', children used their extended knowledge around the water cycle and proposed ways of representing and experimenting with the phenomenon using digital tools (e.g. the interactive whiteboard). Collaboration and teamwork played a significant role in this phase too.

## 8.6 Experimentation

During this phase all the expressed ideas are brought to life. Learning by doing is the main method, which allows children to visualise their ideas. The creation of images, stories, diagrams, or multimedia presentations take place during this phase. Children learn while making their ideas tangible and sharing them with other people.

After the presentation of the multimedia application, an experimental application of evaporation and liquefaction took place with the use of everyday materials (pot with boiling water and droplets are formed on the lid). Children initially thought that the droplets that increased as the water boiled came from the boiling water of the pot and not from the steam that liquefied. They understood it after a few tests, when it was ensured that the water in the pot could not touch the lid. They were given the opportunity to experiment with the phenomenon by changing various parameters such as sudden reduction of temperature by placing the hot lid on the freezer (e.g., liquefaction was achieved almost immediately).

After a short discussion with the children, they were divided into small groups and each group decided which stage of the water cycle would like to draw (evaporation—cloud formation—rain—snow etc.) with the drawing software on the interactive whiteboard. Children in each group had important decisions to make around the interactive whiteboard tools that they could use but also about the details of each stage that they needed to draw. Teachers helped them along the way and pointed towards the tools of:

- Pen
- Colors and textures
- Select pen width
- Change background color (Fig. 8.1).

The interactive whiteboard enabled them to draw vertically on a large surface and to share the result of their work with the entire class. In addition, the Zone of Proximal Development (Vygotsky, 1978a, 1978b) was applied within the groups and with the other classmates during the group collaboration. According to Vygotsky (1978a),

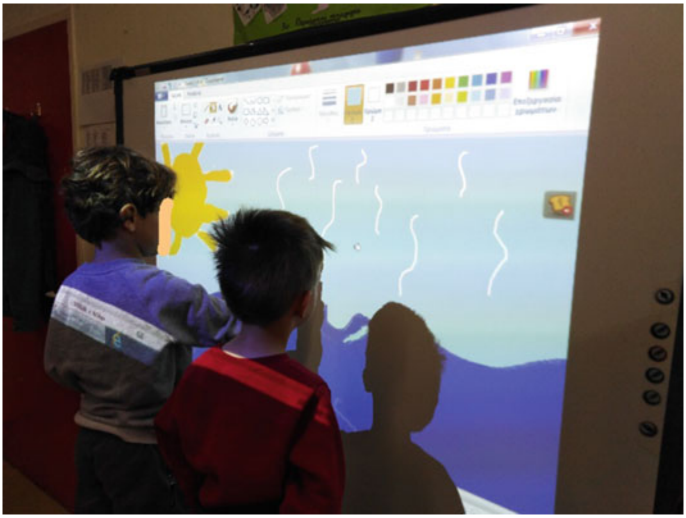

**Fig. 8.1** Children working on the interactive whiteboard

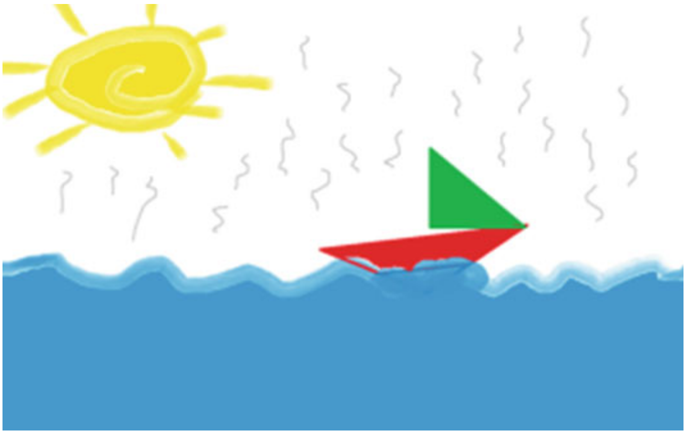

**Fig. 8.2** The stage of evaporation

the Zone of Proximal Development has been defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978a, p. 86). In other words, children's learning occurs through social interaction with a skillful tutor. Scaffolding within the Zone of Proximal Development supported children's reasoning and maximized the potential learning opportunities. The whiteboard was a good incentive for them to work together and share their thoughts and ideas (Figs. 8.2, 8.3, 8.4 and 8.5).

Drawings were saved and revisited before moving to the next step. Each group described its drawing using the corresponding terminology and explained the stage in the water cycle, how and why they selected to present the stage.

When all drawings were complete, children with the help of their teachers used the Story Jumper application for the creation of a digital storybook and monitored the whole result of their work in the interactive whiteboard in order to review and reflect on their learning. Finally, the digital story book was shared between the three kindergartens, the parents of the children and the schools' webpage.

**Fig. 8.3** Clouds creation

**Fig. 8.4** Rainfall

**Fig. 8.5** Snow crystals

## 8.7 Evolution

According to the IDEO model (Fierst et al., 2011), the last phase of the design thinking implementation includes a reflection on a future pedagogical implementation. A final brainstorming discussion took place and children answered the basic questions describing the elements of the water cycle and the natural properties of water. Their answers were digitally recorded, and the questions were the following:

- Where do we find water?
- Where does rain and snow come from?
- What are clouds made of?
- How is rain created?
- What is snow made of?
- How is snow created?

All these questions had been answered during the discovery phase and the answers formed the first concept map. The teachers displayed the first concept map and read the answers (Fig. 8.6).

Through these questions the children were asked to do the following:

- to compare the first and the final concept map,
- to recall experiences of conceptual change and the way in which these changes appeared in their group work,
- to identify how they contributed to the conceptual change or process,
- to express their emotions about the design process and the result, and
- to express relevant issues for further exploration according to their interests.

The aim of these questions was not to merely depict the metacognitive elaboration of the scientific concepts, but to reveal their view on the learning process in which the children actively participated. Through these questions the children were guided to think about the following:

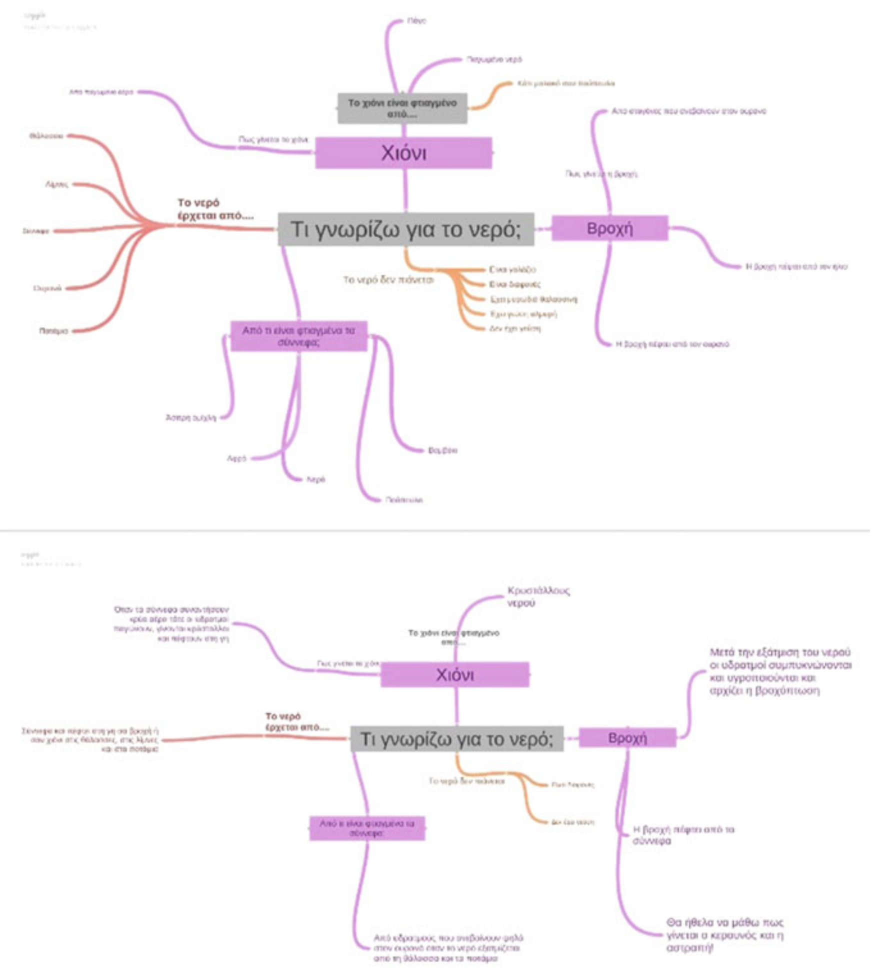


**Fig. 8.6** The 1st and 2nd concept maps created based on the children's answers

- to review their learning process,
- to realize the cognitive modification of their prior false ideas or perceptions,
- to point out the enrichment of their prior knowledge,
- to evaluate their contribution to the design process, and
- to express their feelings in relation to the project's theme and what they would improve if they could do it again.

Indicative questions and answers of children:

(a) Teacher: I will read from the map what you thought about water. I want you to identify the differences between what you know now and what you knew before. What is the most important change?

'I know many things now, the second map does not have so many "legs", but we all know the same things.' (Kostas).

(b) Teacher: How do you think you helped when we learned all these?

'We were quiet and watched the videos and played nicely with the games' (Maria).

(c) Teacher: Do you remember a game that we did that helped you understand how water changes?

'The video that explained the evaporation and how the rain is created and when we did the experiment with the boiling water and I saw the liquefaction' (Anestis).

(d) Teacher: How do you feel about everything we did and everything you have learned?

'I feel very nice, I want to see the videos again and to make a story again. Send the videos to my mom, I want to watch them with her. Send the storybook too!' (Katerina).

(e) Teacher: What else would you like to do and what to research?

'I want to know how lightning strikes!' (Tasos).

This activity promoted children's confrontation of their initial ideas and false believes with their final representations and ideas. Therefore, metacognitive processes were promoted and the emphasis on the learning process (not the product) was ensured.

## 8.8 Discussion

The design thinking process proved very useful for teachers to co-ordinate the project and for ensuring children's active involvement in the whole process. As detailed in each phase the aims were achieved, and children's scientific knowledge was deepened and enriched. The digital tools used were also very helpful and added to children's digital competencies. In line with previous research, children through the design thinking process were introduced smoothly to the scientific way of research and at the same time they deepened their understanding around the phenomenon (Yalçın & Erden, 2021). They used the computer, the interactive whiteboard and interacted with different kinds of software (Coggle, MS Painting, Story Jumber) in small groups with the assistance of their teachers. Digital technologies offered a useful terrain for cooperation among children (teamwork in small groups) and between teachers and children. Engagement with peers in a small group is found to be beneficial in comprehending complex concepts, such as the water cycle (Ahi, 2017; Chang, 2012; Vo et al., 2015).

During the first two phases, a series of key open-ended questions helped the expansion of the discussion. In line with previous research on children's learning about the natural environment, teachers effectively supported children to connect the new experience and knowledge with previous experiences and preexisting knowledge by using inferential questioning (Lee et al, 2012; Zurek et al., 2014). Generally, the importance of student–teacher dialogues in science education for learning concepts regarding natural phenomena, such as 'the water cycle' is stated in prior studies (Christidou & Hatzinikita, 2005; Strang & Aberg-Bengtsson, 2010). This study is in line with previous suggestions but offers new insights of how to use popular digital tools and software to stimulate these dialogues. Additionally, the organisation of questions and children's responses contributed to the formation of two concept maps which were useful not only for representing children's views but also for self-assessment and self-reflection in the final phase of evolution. In line with previous studies, design thinking enhanced the relationships of teachers and students (Carroll, 2015).

Based on the concept map, the selected simulations reconstructed children's alternative perceptions and provided well-grounded scientific explanations. For example, children reported that water disappears with evaporation. This was in line with previous research that stated the difficulties that young children encounter in understanding of evaporation (Bar, 1989; Saçkes et al., 2010). According to Bar (1989) evaporation can be understood only after children have understood the state changes of the matter. The creation of the final map revealed that children's knowledge on the topic was now clear and unambiguous. The goals that were set were achieved in their entirety. Specifically: (a) children understood through the multimedia applications (simulations and videos) the origin of rain from the clouds and not from the sky, the sun, etc. (b) after the experimentation children understood the water cycle and reported the changes in water properties (solid form—snow). This information was not presented in the multimedia application (video or simulation) (c) the simulation gave children the opportunity to experiment with the factors (wind, temperature, humidity) that affect the phenomenon of evaporation. They investigated various hypotheses about the intensity of the phenomenon (e.g., When does more water evaporate? or How do clouds form?).

The multimedia applications supported the visualisation of the water cycle and gave children opportunities of making hypotheses, testing their ideas, and experiment with the phenomenon. Digital technologies helped children to understand the phenomenon in depth through experimentation in a macroscopic level. They made assumptions about the change of the parameters, observed the effect of their choices, and thus enhanced their decision-making. Finally, the interactive board gave children the opportunity to collaborate, interact socially and to communicate their ideas and views. The painting software promoted personal expression after the discussion and increased the exchange of ideas between the members of each group.

The digital story book of the phenomenon served as an accurate evaluation of the process. During the creation of the digital story book, children narrated the stages of the natural phenomenon and processed verbally the information. They freely rehearsed the new knowledge using accurate scientific expressions. They had the opportunity to use the vocabulary in a substantial context within their group drawings.

Finally, children compared the two concept maps (first and final) and realized the modifications of their initial representations around water. With this process they explained again the phenomenon and clarified any relevant queries. They expressed positive feelings about the newly acquired knowledge and the design thinking process. They also presented their ideas for a new investigation and proposed interesting ways to further improve future design thinking endeavours.

In the ideation phase experiments were organised even though they were not included in the original design; however, children's ideas revealed their cognitive need to visualise the changes of natural properties of water. They watched the digital representation of the phenomenon, but the empirical approach seemed equally important. These simple experiments reinforced children's learning in a more practical manner enhancing their scientific thinking; they hypothesised and made predictions of the upcoming results before drawing their conclusions. This was in line with previous studies, where the knowledge generated within simulations was significant and was transferred from the simulations to "real world" tasks with similar characteristics (Falloon, 2020).

Children's extension of ideas, enhanced understanding and sustained interest was evident through their desire to draw the phenomenon as well as the preparation of the digital story book about what they have learned. Their familiarity with the interactive whiteboard led them to select it for the artistic representation of the water circle. Prior studies (Ahi, 2017; Chang, 2012; Smith & Samakarou, 2016) showed how drawings were an appropriate strategy when teaching the water cycle to young children. Consistent with previous research which supports the utilisation of interactive boards with young children we also concluded that: 'The use of drawing as a scaffolding tool made the interactive moments between the adults and children playful and relaxing. Yet, interactions were meaningful, purposeful, educational, worthwhile, and the learning gained through interactive communication was significant' (Chang, 2012, p. 193). However, in our study we found that group drawings focused on the water cycle as a natural phenomenon (evaporation-clouds, formation-rain-snow) and did not explain the natural properties of water (liquid–solid-steam). This contradicts the finding that in some cases, children interpret that the goal of the lesson is the understanding of the individual parts of the cycle water rather than, the actual cycle holistically (Strang & Aberg-Bengtsson, 2010).

Overall, consistent with the constructivist theory, teachers took in careful consideration children's prior experiences and their prior alternative representations and used questions to reconstruct children's perceptions and to expand, build on their previous knowledge. They were aware that knowledge is a cognitive construct emerging as a result of psychological processes (Ausubel, 2000) and that learning of physical concepts occurs with the connection of prior knowledge with new information (Dejonckheere et al., 2016; Driver & Bell, 1986; Driver & Oldham, 1986). Teachers' guiding, supportive and coordinating role was in line with, Vygotsky's (1978b) emphasis on culture, social interaction and communication for formulating cognitive constructs.

Summarising, the design thinking approach in this study proved that young children are capable to experience learning and address challenges connected with a scientific research method in their search for knowledge. The design phases revealed children's cognitive needs and supported their expression of interests and new ideas. Thus, the IDEO model contributed significantly to the achievement of the learning outcomes. Children were involved in brainstorming throughout the process and participated actively. Digital technologies played a key role in the whole process, served as stimuli and provided opportunities for children to act as researchers, designers, artists, problem solvers and disseminators of new knowledge. The design thinking approach was adopted and utilised easily due to the flexible pedagogical atmosphere of early childhood education. The application of this design thinking model contributed to promoting children's critical and creative thinking, problem solving and collaboration, that are basic life, learning and mental skills as underlined in the new reform agenda of the MoE.

The present findings showed that the IDEO model may have rich potential for a more extensive application in teaching science concepts and phenomena in early childhood education. The role of digital technologies was also pivotal in this study and can offer very useful ways of engaging with science and abstract, difficult concepts. This study is one of the few attempts to examine design thinking in young children, an emerging area of research which will grow even more in near future. Future research may involve studying the model's usefulness in exploring other important scientific fields in early childhood education such as environmental education, sustainability and others.

## 8.9 Limitations

The small sample size and the convenience type of sampling limit the generalisability of this study's findings. However, this is a common limitation in small case studies with no funding. As discussed in the introduction, there is a dearth of research around science, design thinking and very young children so exploratory studies could offer useful insights and recommendations in this field. Another limitation that should be mentioned is that the participating kindergartens had a better than average standard of digital equipment which surely contributed to completing this project successfully. Teachers who were involved were also confident and well-trained in using new technologies. Results might be different in more disadvantaged areas or when educators are not as experienced in implementing innovative teaching approaches and digital technologies.

Moreover, there were certain challenges that teachers faced during the implementation of the IDEO model in everyday practice. The first one concerned the interaction with the new curriculum agenda and the need to associate it with children's interests and the desires. It was important to focus on an interesting topic for the children that would also provide enough teaching and learning opportunities for the development of leaning, mind, technology, and science skills. Contextual restrictions (e.g., lack of resources, small spaces etc.) also need to be taken into account when implementing design thinking projects. Another limitation was the need for compliance with the kindergarten's rules and with the preschool curriculum. The adoption of novel teaching methods is usually challenging for the teachers (Areljung, 2019). These challenges were addressed at a team level, with the kindergarten teachers driving the process 'which is where grassroots change begins to happen' (Fierst et al., 2011, p. 12). In our study, the design thinking implementation resulted in a holistic change on the interactions between teachers and children and impacted on the kindergartens' teaching philosophy.

## 8.10 Conclusion

Going through the design thinking phases children's creativity and critical thinking skills were promoted and this was obvious when they proposed to recreate the water cycle on the interactive board and to prepare a digital story book which included all their new knowledge, restructured understandings and accurate terminology on the topic. Their problem-solving skills were also enhanced when they were asked to propose ways to experiment with the different states of water in the classroom using everyday materials and being able to account for different variables and results. Young children were capable to follow the different phases developing communication and collaboration skills and teachers were given the opportunity to coordinate the scientific experiences successfully and efficiently. Thus, the adoption of the design thinking approach in this study proved to be very useful in organizing the whole process.

## References

Ahi, B. (2017). The effect of talking drawings on five-year-old Turkish children's mental models of the water cycle. *International Journal of Environmental and Science Education, 12*(3), 349–367. https://eric.ed.gov/?id=EJ1141375

Areljung, S. (2019). Why do teachers adopt or resist a pedagogical idea for teaching science in preschool? *International Journal of Early Years Education, 27*(3), 238–253. https://doi.org/10.1080/09669760.2018.1481733

Ausubel, D. P. (2000). *The acquisition and retention of knowledge*. Springer.

Bar, V. (1989). Children's views about the water cycle. *Science Education, 73*(4), 481–500. https://eric.ed.gov/?id=EJ394281

Bar, V., & Galili, I. (1994). Stages of children's views about evaporation. *International Journal of Science Education, 16*(2), 157–174. https://doi.org/10.1080/0950069940160205

Ben-zvi-Assarf, O., & Orion, N. (2005). A study of junior high students' perceptions of the water cycle. *Journal of Geoscience Education, 53*(4), 366–373. https://doi.org/10.5408/1089-9995-53.4.366

Campbell, C., & Jobling, W. (2021). Effective science learning environments. In C. Campbell, W. Jobling, & C. Howitt (Eds.), *Science in Early Childhood* (pp. 80–92). Cambridge University Press.

Care, E., Kim, H., Vista, A., & Anderson, K. (2018). *Education system alignment for 21st century skills: Focus on assessment*. Center for Universal Education at The Brookings Institution.

Carroll, M. (2015). Stretch, dream, and do-a 21st century design thinking and STEM journey. *Journal of Research in STEM Education, 1*(1), 59–70. https://doi.org/10.51355/jstem.2015.9
Chang, N. (2012). The role of drawing in young children's construction of science concepts. *Early Childhood Education Journal, 40*, 187–193. https://doi.org/10.1007/s10643-012-0511-3
Christidou, V., & Hatzinikita, V. (2005). Preschool children's explanations of plant growth and rain formation: A comparative analysis. *Research in Science Education, 36*, 187–210. https://doi.org/10.1007/s11165-005-9006-1
Christidou, B., Kakana, D.-M., Dimitriou, A., & Bonoti, F. (2003). Teaching activities in preschool children: The phenomenon of rain. In *1st Panhellenic Conference with International Participation and Topic: The Teaching of Natural Sciences in the Information Society* (pp. 53–58). Grigoris [In Greek].
Cohen, L., Manion, L., & Morrison, K. (2017). *Research methods in education* (8th ed.). Routledge
Council of Europe. (2018). *Reference framework of competences for democratic culture.* Council of Europe Publishing. https://rm.coe.int/prems-008318-gbr-2508-reference-framework-of-competences-vol-1-8573-co/16807bc66c
Curran, F. C., & Kitchin, J. (2019). Early elementary science instruction: Does more time on science or science topics/skills predict science achievement in the early grades? *AERA Open, 5*(3). https://doi.org/10.1177/2332858419861081
Dejonckheere, P. J., De Wit, N., Van de Keere, K., & Vervaet, S. (2016). Exploring the classroom: Teaching science in early childhood. *International Electronic Journal of Elementary Education, 8*(4), 537–558. https://eric.ed.gov/?id=EJ1109852
Dotson, M. E., Alvarez, V., Tackett, M., Asturias, G., Leon, I., & Ramanujam, N. (2020). Design thinking-based STEM learning: Preliminary results on achieving scale and sustainability through the IGNITE model. *Frontiers in Education, 5*, 14. https://doi.org/10.3389/feduc.2020.00014
Driver, R., & Bell, B. F. (1986). Students' thinking and the learning of science: A constructive view. *School Science Review, 67*, 443–456. https://eric.ed.gov/?id=EJ338119
Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education, 13*, 105–122. https://doi.org/10.1080/03057268608559933
Falloon, G. (2020). From simulations to real: Investigating young students' learning and transfer from simulations to real tasks. *British Journal of Educational Technology, 51*(3), 778–797. https://doi.org/10.1111/bjet.12885
Fierst, K., Diefenthaler, A., & Diefenthaler, G. (2011). *Design thinking for educators.* IDEO.
Hatzigianni, M., & Kalaitzidis, I. (2018). Early childhood educators' attitudes and beliefs around the use of touchscreen technologies by children under three years of age. *British Journal of Educational Technology, 49*(5), 883–895. https://doi.org/10.1111/bjet.12649
Hendry, G. D. (1996). Constructivism and educational practice. *Australian Journal of Education, 40*(1), 19–45. https://doi.org/10.1177/000494419604000103
Inter-Agency and Expert Group on SDG Indicators. (2017). *Report of the inter-agency and expert group on sustainable development goal indicators* (E/CN.3/2017/2), Annex III. https://unstats.un.org/sdgs/indicators/Official%20Revised%20List%20of%20global%20SDG%20indicators.pdf
Giezma, A., Malzahn, N., & Hoppe, U. (2013). Mobilogue: creating and conducting mobile learning scenarios in informal settings. In *Proceedings of the 21st International Conference on Computers in Education, Asia-Pacific Society for Computers in Education.* Denpasar Bali, Indonesia.
Global Sustainable Development Goal Indicators-IAEG-SDGs. (2017). https://undocs.org/A/RES/71/313
Grammenos, D. (2016). Future designers: A rollercoaster for the mind. *Interactions*, 58–63. https://doi.org/10.1145/2846695
Guha, M. L., Druin, A., Chipman, G., Fails, J. A., Simms, S., & Farber, A. (2004). Mixing ideas: A new technique for working with young children as design partners. In *Proceedings of the 2004 Conference on Interaction Design and Children: Building a Community* (pp. 35–42).
Juškevičienė, A., Dagienė, V., & Dolgopolovas, V. (2021). Integrated activities in STEM environment: Methodology and implementation practice. *Computer Applications in Engineering Education, 29*(1), 209–228. https://doi.org/10.1002/cae.22324

Kalogiannakis, M., Ampartzaki, M., Papadakis, S., & Skaraki, E. (2018). Teaching natural science concepts to young children with mobile devices and hands-on activities. A case study. *International Journal of Teaching and Case Studies, 9*(2), 171–183. https://doi.org/10.1504/IJTCS.2018.090965

Kavousi, S., Miller, P. A., & Alexander, P. A. (2019). Modeling metacognition in design thinking and design making. *International Journal of Technology and Design Education, 30*(4), 709–735. https://doi.org/10.1007/s10798-019-09521-9

Kimbell, L. (2016). Rethinking design thinking: Part II. *Design and Culture, 4*(2), 129–148. https://doi.org/10.2752/175470812X13281948975413

Lai, C.-L., & Hwang, G.-J. (2014). Effects of mobile learning time on students' conception of collaboration, communication, complex problem-solving, meta-cognitive awareness and creativity. *International Journal of Mobile Learning and Organisation, 8*(3–4), 276–291. https://doi.org/10.1504/IJMLO.2014.067029

Lee, Y., Kinzie, M. B., & Whittaker, J. V. (2012). Impact of online support for teachers' open-ended questioning in pre-k science activities. *Teaching and Teacher Education, 28*(4), 568–577. https://doi.org/10.1016/j.tate.2012.01.002

Loveless, A. (2002). *Literature review in creativity, new technologies and learning. A NESTA*. Futurelab research report 4.

Loveless, A. M. (2008). Creative learning and new technology? A provocation paper. In J. Sefton-Green (Ed.), *Creative Learning* (pp. 61–72). Creative Partnerships.

Mantouvalos, S. (2012). *The cloud that cried*. Patakis [In Greek]

McClure, E. R., Guernsey, L., Clements, D. H., Bales, S. N., Nichols, J., Kendall-Taylor, N., & Levine, M. H. (2017). *Stem starts early: Grounding science, technology, engineering, and math education in early childhood*. The Joan Ganz Cooney Center at Sesame Workshop.

Miner, J. T. (1992). *An early childhood study of the water cycle*. https://digitalscholarship.unlv.edu/cgi/viewcontent.cgi?article=1241&context=rtds

Ministry of Education-MoE. (2014). Early childhood curriculum. In *New School-21st Century School* [In Greek].

Ministry of Education-MoE. (2020). *Skills laboratories*. Law 4692/26-2-2020 [In Greek].

Osborne, R. (1982). Conceptual change-for pupils and teachers. *Research in Science Education, 12*, 25–31. https://doi.org/10.1007/BF02357010

Papadopoulos, P., & Seroglou, F. (2007). A progressive sequence of theatre techniques for teaching science. *Argumentation, 78*(70), 74.

Roschelle, J., & Clancey, W. J. (1992). Learning as social and neural. *Educational Psychologist, 27*(4), 435–453. https://doi.org/10.1207/s15326985ep2704_3

Saçkes, M., Flevares, L., M., & Trundle, K. C. (2010). Four to-six-year-old children's conceptions of the mechanism of rainfall. *Early Childhood Research Quarterly, 25*, 536–546. https://doi.org/10.1016/j.ecresq.2010.01.001

Savva, S. (2014). Year 3 to year 5 children's conceptual understanding of the mechanism of rainfall: A comparative analysis. *Ikastorratza e-Revista de Didáctica, 12*. http://www.ehu.es/ikastorratza/12_alea/rainfall.pdf

Shively, K., Stith, K. M., & Rubenstein, L. D. (2018). Measuring what matters: Assessing creativity, critical thinking, and the design process. *Gifted Child Today, 41*(3), 149–158. https://doi.org/10.1177/1076217518768361

Simeon, M. I., Samsudin, M. A., & Yakob, N. (2020). Effect of design thinking approach on students' achievement in some selected physics concepts in the context of STEM learning. *International Journal of Technology and Design Education*, 1–28. https://doi.org/10.1007/s10798-020-09601-1

Siang, T. Y. (2017). *5 Stages in the design thinking process*. Interaction Design Foundation. https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process

Smith, L. L., & Samarakoon, D. (2016). Teaching kindergarten students about the water cycle through arts and invention. *Journal of STEM Arts, Crafts, and Constructions, 2*(1), 5.

Strang, M. H., & Aberg-Bengtsson, L. (2010). "Where do you think water comes from?" Teacher-pupil dialogues about water as an environmental phenomenon. *Scandinavian Journal of Educational Research, 54*(4), 313–333. https://doi.org/10.1080/00313831.2010.493340

Strimel, G. J., Kim, E., Grubbs, M. E., & Huffman, T. J. (2020). A meta-synthesis of primary and secondary student design cognition research. *International Journal of Technology and Design Education, 30*(2), 243–274. https://doi.org/10.1007/s10798-019-09505-9

van Tuijl, C., & van der Molen, J. H. W. (2016). Study choice and career development in STEM fields: An overview and integration of the research. *International Journal of Technology and Design Education, 26*(2), 159–183. https://doi.org/10.1007/s10798-015-9308-1

Vo, T., Forbes, C., T., Zangori, L., & Schwarz, C. V. (2015). Fostering third-grade students' use of scientific models with the water cycle: Elementary teachers' conceptions and practices. *International Journal of Science Education, 37*(15), 2411–2432. doi:https://doi.org/10.1080/09500693.2015.1080880

Vygotsky, L. S. (1978a). In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society: The development of higher psychological processes*. Harvard University Press.

Vygotsky, L. S. (1978b). Interaction between learning and development. *Readings on the Development of Children, 23*(3), 34–41.

Wind, S. A., Alemdar, M., Lingle, J. A., Moore, R., & Asilkalkan, A. (2019). Exploring student understanding of the engineering design process using distractor analysis. *International Journal of STEM Education, 6*(1), 1–18. https://doi.org/10.1186/s40594-018-0156-x

Yalçın, V., & Erden, Ş. (2021). The effect of STEM activities prepared according to the design thinking model on preschool children's creativity and problem-solving skills. *Thinking Skills and Creativity, 41*. https://doi.org/10.1016/j.tsc.2021.100864

Zurek, A., Torquati, J., & Acar, I. (2014). Scaffolding as a tool for environmental education in early childhood. *International Journal of Early Childhood Environmental Education, 2*(1), 27–57. https://eric.ed.gov/?id=EJ1108033

## *Internet Sources*

Digital story. https://www.storyjumper.com/book/index/68258405

'Photodentro' Educational platform of the Greek Ministry of Education. *The water cycle*. http://photodentro.edu.gr/lor/handle/8521/1333

'Photodentro' Educational platform of the Greek Ministry of Education. *The phenomenon of evaporation*. http://photodentro.edu.gr/lor/handle/8521/7999

NASA. *The water cycle*. https://pmm.nasa.gov/education/videos/water-cycle-animation

USA Environmental Protection Agency. *The water cycle*. https://www3.epa.gov/safewater/kids/flash/flash/flash_watercycle.html. Ackermann, E. (2001). Piaget's constructivism, Papert's constructionism: What's the difference. *Future of Learning Group Publication, 5*(3), 438.

# Chapter 9
# Creative Learning with Technologies in Young Students' STEAM Education

**Kaiju Kangas, Kati Sormunen, and Tiina Korhonen**

**Abstract** The STEAM approach combining science, technology, engineering, arts, and mathematics is a promising method for promoting students' creative technological competencies, but it has received little research interest in the field of early education. This chapter explores this approach in pre-school and grades 1 and 2 of primary school (ages 6–8), and examines how creative use of technologies is related to various learning areas in young students' learning projects. We present 13 interdisciplinary projects in which invention pedagogy, a Finnish approach to STEAM education, was implemented. Invention pedagogy emphasizes the learning of twenty-first century competencies through multidisciplinary, creative, technology-enhanced design and creative processes. Three data sets (i.e., teachers' project plans, descriptions and reflections) and visual representations of the projects, were analyzed with qualitative content analysis and co-occurrence network analysis. The findings indicate that young students are able use various technological activities representing five technological dimensions: crafting, design, engineering, documenting and sharing, and programming. The underlying connections between the activities and implemented learning areas revealed three orientations to STEAM education: the maker orientation, competence orientation, and digital orientation. These orientations represent varying emphases of young students' STEAM education and suggest new directions for further developing the approach.

**Keywords** STEAM education · Creative technology · Pre-primary education · Primary education · Invention pedagogy

## 9.1 Introduction

For the past several years, educational research in many countries has highlighted the interdisciplinary nature of knowledge and learning of twenty-first century competencies. Creativity and digital competence in particular have been brought to the

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forefront as requisite attributes of competent future citizens. It has been argued that we need to educate, from early years on, citizens of the future who can understand, reflect critically, and influence creatively the technologically changing world (e.g., Organisation for Economic Co-operation and Development (OECD), 2019). Technology has quickly become a part of young children's lives, and technological change already reflects strongly in children's ways of playing, the most natural way to be and live and perceive the world, and thus, construct knowledge. Therefore, it is only natural that technology is present in contemporary children's play as a tool or theme (Slutsky & DeShelter, 2017). Thus, technology education has been emphasized as necessary in early years education (Fleer, 2011; Marsh, 2015; Sundqvist & Nilsson, 2018).

Young students' technology education aims to help children understand everyday technologies and how these can be used to solve daily life problems and invent one's creative solutions (Fox-Turnbull, 2019). In Finland, pedagogical activities in technology education emphasize child-centered ways of working, use of imagination, and constructive play (Finnish National Board of Education (FNBE), 2016b; Turja et al., 2009). Children are encouraged to observe and marvel at the surrounding technology and technological implementations and ask related questions. Their interest towards technology is evoked in practical, hands-on ways. Young students' technology education emphasizes human activity, inquiry-based and experimental activities, and innovative solutions (Kilbrink et al., 2014). The focus of educating twenty-first century citizens is not to teach them how to use technological devices and consume content, but learn to apply and create new value with technology. Early technology education is wide-ranging and practical education that is intertwined with design, engineering, and scientific practices, as well as interdisciplinary approaches (Quinn & Bell, 2013). It includes creative problem solving and designing, inquiring, experimenting with structures and materials, hands-on making, as well as reflection on the process and outcomes. Educators should support children to find their technological problems and encourage them to examine and make various constructions or solutions to these problems using versatile materials and tools (FNBE, 2016a, 2016b; Turja et al., 2009).

There is a highly similar emphasis in the integrative STEAM approach (science, technology, engineering, arts, and mathematics), which is regarded as promising for enhancing students' creative technological competencies starting from the early stages of education (Lindeman et al., 2014). In STEAM, the 'A' refers to arts, design, and the humanities, changing the focus from technology education as applied science towards more multidisciplinary and creative problem solving (Jones et al., 2013). The STEAM approach is often understood as adding the artistic or creative process and perhaps design thinking as part of STEM education (Bequette & Bequette, 2012). However, the full potential of STEAM cannot be justified in terms of what the "A" can do for mathematics or science, but rather in terms of what it directly delivers (Hetland et al., 2013). Art and other creative approaches to education have a learning heuristic where experience-based practices are used for problem-solving, learning, investigating, and discovery. The practices include, for example, envisioning mentally what cannot be directly observed or imagining possible next steps, expressing ideas or personal meanings, exploring playfully without a pre-structured plan, and embracing mistakes as learning opportunities (Daugherty, 2013).

However, the STEAM approach among young students has gained only little interest in research, and the empirical evidence of its application is particularly limited. In the present chapter, our aim is to understand how teachers apply integrative, technology-enhanced STEAM projects in pre-primary education and grades 1 and 2 of primary school (age 6–8). In the following section, we first briefly explore technology education and its objectives in early childhood education and introduce the Finnish perspective to young students' STEAM education. Then, we ground the present chapter in the longstanding research and development of invention pedagogy, a Finnish approach to STEAM education, for teaching and learning twenty-first century competencies through multidisciplinary, creative technology-enhanced design and making processes in formal educational settings. We present 13 invention projects where invention pedagogy was implemented in pre-primary education and grades 1 and 2 of primary school, and examine the creative use of technologies in relation to the learning areas implemented in the projects. We pose the following research questions:

1. What kind of creative technological activities were implemented in pre-and primary school invention projects?
2. How were the creative technological activities related to the learning areas pursued in the projects?

## 9.2 Technology Education in Early Childhood

The ability to use technology interactively is one of the key competencies that students need to learn for a successful life in a well-functioning modern society (OECD, 2019). Technology plays an increasingly important role, for example, in transmitting information, in communication, and in routine work, which should be considered in all aspects of teaching. In the field of STEM education, the use of digital technology has been studied quite extensively (e.g., Li et al., 2020). In recent years, research interest towards harnessing physical tools for promoting creativity and inquiry in conventional STEM education for young learners has risen. According to Fox-Turnbull (2019), teachers recognize the importance of creativity within technological practices in young students' technology education. Creativity, imagination and playfulness are essentials when working with new tools and materials. Furthermore, they improve practical and physical skills for using digital technologies as well as art and craft tools, and foster meaning-making when manipulating materials and creating artefacts (OECD, 2019).

Interesting experiments have been conducted and promising results found in this relatively new field of research. The findings indicate that participating in iterative design processes and using a wide variety of technologies has been beneficial for young students' learning. For example, Kalmpourtzis (2019) found that designing games can foster intrinsic motivation and positively impact young students' cognitive development, particularly their thinking skills related to mathematics, such as skills and strategies for problem-solving and problem-posing. Papadakis et al. (2016) have similar notions from preschoolers' animation and game making with ScratchJr. Their findings indicate that teaching programming concepts to young children positively influences the development of basic cognitive skills associated with mathematical ability and logical thinking. The results of a study by Kewalramani et al. (2020) reveal that technology constructed play experiences with robotic toys and littleBits electronic and magnetic blocks supported young students' scientific inquiry, design thinking, and creativity as well as scientific vocabulary. Furthermore, Hatzigianni et al. (2021) found that during a 3D design process, various STEAM activities invoked young students' creative and critical thinking as well as problem-solving and decision-making skills. In a related study, they interviewed children who participated in the 3D designing project and found that children could describe challenging and rewarding aspects of their design, identify solutions, offer alternatives, and brainstorm new ideas (Hatzigianni et al., 2020).

However, the aforementioned studies as well as others demonstrate that recent research of young students' technology education has a strong emphasis on digital technologies. In early learning settings, analog and more traditional technologies still play an essential role, and they can be equally important for developing children's technological competence and other twenty-first century skills. The focal question is not the superiority of some technologies over others, but how can we best support children to develop their own creative ideas through technological means. A broad approach to technology education provides children the opportunity to understand the all-pervasive and daily apparent nature of technology. In the following, we describe the multidisciplinary and multimaterial context of technology education in Finland.

## 9.3 Finnish Perspective on Young Students' STEAM Education

In Finland, early childhood education (ages 0–5), pre-primary education (age 6) and basic education (i.e., primary and lower secondary education, ages 7–16) each have their own national curricula; however, they are thematically linked to support children's and adolescents' continuous learning. Technology education is not an individual subject but rather a multidisciplinary and cross-curricular learning entity at all levels of education. This is underlined in the curricula in several contexts, from the basic values to the general competence objectives, and to many individual subjects. Traditionally, and still today, it is strongly connected to craft education, a mandatory school subject for all students in grades 1–7. Craft as a school subject provides the means for creative ideation and experimentation with technologies, for developing students' understandings of the technological world (FNBE, 2016a). In the latest basic education curriculum reform in 2014, textile craft and technical craft were combined as one, multimaterial craft in which "activities are based on craft expression, design, and technology" (FNBE, 2016a, p. 146; see also Kokko et al., 2020). The early childhood and pre-primary curricula were organized into five interdisciplinary core entities (FNAE, 2018; FNBE, 2016b). Technology education is particularly present in the entities *Exploring and interacting with my environment*, which emphasizes STEM subjects and related skills and practices, and *Diverse forms of expression*, which includes music, visual arts, crafts, and physical and verbal expression. In pre-primary and basic education, the concept of holistic craft is emphasized (i.e., a student or group is responsible of the whole craft process from ideation and design to making and evaluation) (see Pöllänen, 2009). During the one-year pre-primary school, children undergo at least one holistic and long-term craft process under teacher's supervision (FNBE, 2016b). From time to time, the question of technology education as a stand-alone school subject is raised. Proponents argue that technological literacy is one of the core skills needed today and in the future, and thus it should be taught on its own. However, as reflected in the national curricula, a future-oriented approach to technology requires a broader, multidisciplinary perspective and strong connections to twenty-first century competencies (cf. Kokko et al., 2020).

In addition to technology education, the multidisciplinary premise is visible all over the Finnish curricula, from early childhood to basic education. The core entities provide a rich thematic arena for early childhood educators to build creative STEAM projects with students. In the first years of primary school, more subject-oriented learning starts to take place; however, strong connections between various subjects are still emphasized. For example, environmental studies is an integrated subject combining the fields of biology, geography, physics, chemistry, and health education, with viewpoints from both natural and human sciences (FNBE, 2016a). The subject emphasizes learning tasks connected to everyday life, use of scientific and engineering practices and technology, and engagement through scientific questions and problem-solving activities (Lavonen et al., 2021). In addition, at the primary and secondary level interdisciplinarity is encouraged by an obligation to organize multidisciplinary learning modules at least once during each school year. Multidisciplinary learning modules promote achieving the set educational objectives when schools and teachers define the goals and contents of the modules by integrating various subjects and twenty-first century competences.

The contents of each curriculum are framed by the concept of transversal competence, the Finnish interpretation of twenty-first century skills (Binkley et al., 2012). The concept refers to "an entity of knowledge, skills, values, attitudes, and will" (FNBE, 2016a, p.36) needed in modern society and in the future. Depending on the level of education, the concept is organized around six or seven themes: (1) thinking and learning to learn, (2) cultural competence, interaction and self-expression, (3) taking care of oneself and managing daily life, (4) multiliteracy, (5) ICT competence, (6) working life competence and entrepreneurship, and (7) participation, involvement and building a sustainable future (FNBE, 2016a). In early childhood and pre-primary curricula, the theme (6) working life competence and entrepreneurship is omitted, and the other themes are described in a slightly modified manner more suitable for younger students. In early education, the transversal competence themes are approached in child-centered and integrative ways, often combining children's interests with the objectives of the curriculum. The aim is to support children's personal growth, lifelong learning, working life, and civic activity in the twenty-first century (cf. Kumpulainen & Sefton-Green, 2019).

The future-oriented curriculum, combined with an integrative STEAM approach, provides a fruitful basis for implementing transversal and multidisciplinary technology training. The essence of STEAM, and young students' technology education, is in creative actions and perceiving children as active constructors of their environment. Enabling children to use technologies in creative ways at an early stage of education is a crucial part of developing the competences needed in the society and working life of the future (Papavlasopoulou et al., 2017). Learning by creating, making, and constructing various structures and solutions from a variety of materials facilitates children's evolving understanding of technology as an outcome of creative human activity (FNBE, 2016a, 2016b). Documenting and verbalizing the solutions they have made also provides children with a basis for critical reflection on technological solutions in general. Moreover, comprehensive and creative technology education provides children with a wide variety of opportunities to be inspired and interested in the possibilities of technology.

## 9.4 Methodology

### *9.4.1 The Context and Participants: Implementing STEAM Through Inventing*

To implement STEAM-oriented multidisciplinary learning and the curriculum, our research group, together with teachers, has developed invention pedagogy at various educational levels for several years (e.g., Riikonen et al., 2020a). Invention pedagogy combines evidence-based teaching and learning strategies for knowledge-creation (Paavola & Hakkarainen, 2014), collaborative designing (Seitamaa-Hakkarainen et al., 2010), creative problem-solving in science and technology education (Lavonen et al., 2004), and support for learning (Sormunen et al., 2020). Through the invention process, students learn to deal with challenging scientific, technological, and design problems and collaboratively develop creative solutions using various digital and traditional technologies. Every student is an inventor, a maker, who is encouraged to share his or her knowledge when constructing a shared artefact (Riikonen et al., 2020b). The invention process follows a loose structure with seven phases: (1) Orientation to the theme and team working, (2) defining the invention challenge, (3) ideation, information gathering, and idea evaluation, (4) testing and elaborating the ideas, (5) evaluating the design, (6) elaborating the design, prototyping, and constructing the invention, and (7) presenting and evaluating the final invention. However, the process is non-linear and iterative in nature; the phases are not a prescription of rigidly specified stages and can vary from one project to another. In this regard, invention projects are multidisciplinary projects combining craft, design, and technology education, STEM-education, art education and many other learning areas.

Over the years, the teachers and researchers have together organized dozens of STEAM-oriented invention projects in schools. All teachers have participated in 2–4 workshops organized by our research group, focusing on the creative invention process and suitable technologies. Here, we employ a collective case study approach (Goddard, 2010) and focus on 13 projects conducted in pre-primary schools, or grades 1 and 2 in primary schools. Some projects also included a few younger or older children, but most participants were 6–8 years old. The main goal of collective case study is to explore cross-case comparisons and draw generalizations from the entire group of cases to deeply understand the phenomenon from a variety of perspectives; the cases may or may not locate in one site (Goddard, 2010). The projects, the participating children, and the duration of the projects are presented in Table 9.1. The projects varied in nature; some were shorter projects focusing on creating individual inventions (e.g., Moving toys) while others lasted several weeks and included varying joint activities of the whole group (e.g., Garden plot). In most of the projects, several teachers and classes from the school participated (e.g., Everyday inventions), but some were organized by one teacher in one class (e.g., Two worlds). This was the first time all of the teachers had used invention pedagogy.

### *9.4.2 Data and Analysis*

The projects were conducted during the years 2017–2020, and therefore during several research projects various data types were collected. For the present study, we selected three data sets available from each project, including (1) teachers' project plans, (2) teachers' descriptions and reflections, and (3) visual representations of the projects. The descriptions and reflections were written either by the teachers with the help of some structure and guidelines from the researchers, or by researchers who conducted teacher interviews. The visual representations included, depending on the project, photos of students' finished products and work in progress or videos where students explained their inventions.

Our aim was to analyze how the creative technological activities implemented in the projects were related to the projects' learning areas. We employed a qualitative content analysis (Stake, 2005) in which theory guided the analysis that was complemented with categories emerging from the data. The analysis was conducted in three stages. We first searched for keywords or visual indicators of technological tools and activities used in the projects. These were categorized under five main categories: (1) crafting, (2) design, (3) engineering, (4) documenting and sharing, and (5) programming. The categories have been developed in our previous work (Korhonen et al., 2020) for outlining five technological dimensions present in the invention projects; however, we slightly modified them to suit young students' projects better.

**Table 9.1** Pre-and primary school invention projects, their participants and duration

| Project title | Description of activities and tools | Participants | | | Duration |
|---|---|---|---|---|---|
| | | N | Grade | Age | |
| Creative cards | Small groups created task cards for unused objects found in the school with art and craft supplies, tablets, and laptops | 50 | Pre-school, 1, 2 | 6–9 | 2 weeks |
| Dream school | Small groups created dream school elements in miniature size with art and craft supplies, electronics, and 3D pens | 20 | 1 | 7–8 | 7 weeks |
| Dream space | Small groups designed dream spaces for the pre-school with art and craft supplies, electronics, and vinyl cutter | 34 | Pre-school | 6–7 | 6 weeks |
| Everyday inventions | Small groups created everyday inventions with art and craft supplies, recycled materials, smart phones and tablets | 110 | 2, 4 | 8–11 | 4 weeks |
| Future city | Small groups created elements for a common miniature city with art and craft supplies, electronics, smart phones, and tablets | 70 | 2, 3 | 8–10 | 6 weeks |
| Garden plot | The group explored growing and taking care of plants with recycled materials, art and craft supplies and Micro:bits | 20 | Early years education, pre-school | 2–6 | 16 weeks |
| Gingerbreads and group skills | Small groups 3D designed and printed gingerbread molds and baked gingerbread | 45 | 1 | 7–8 | 3 weeks |

(continued)

**Table 9.1** (continued)

| Project title | Description of activities and tools | Participants | | | Duration |
|---|---|---|---|---|---|
| | | N | Grade | Age | |
| Moving toy | Students created moving toys with art and craft supplies and recycled materials | 40 | 1 | 7–8 | 3 weeks |
| My neighborhood | Students created elements for a common stop motion animation about their neighborhood in 2050 with art and craft supplies, electronics and robotics | 80 | Pre-school | 6–7 | 3 weeks |
| New pre-school | Small groups created miniature rooms, tools and garden elements for a new pre-school with art and craft supplies, electronics, 3D pens and robotics | 26 | Pre-school | 6–7 | 16 weeks |
| Storytellers | Students created elements for a common stop motion animation "Rulers of the Ice Age" with art and craft supplies and filmed the animation with tablets | 70 | Pre-school, 1 | 6–8 | 6 weeks |
| Techno module | Small groups explored programming with unplugged activities, simple robotics, smart phones, and tablets | 61 | 1 | 7–8 | 1 week |
| Two worlds | Students created miniature worlds with art and craft supplies and electronics around their 3D designed and printed objects | 17 | 1 | 7–8 | 15 weeks |

For example, we renamed the dimension originally named communication and documenting to documenting and sharing, as it better described the activities conducted by the young students and their teachers.

The main categories were then further grouped into thematic sub-categories (i.e., technological activities) which emerged from the data, resulting in 2–5 sub-categories within each main category. Table 9.2 presents all the main and the sub-categories. The main categories, the technological dimensions, are organized in columns from the most frequently used (crafting, left column) to the least frequently used dimension (programming, right column). Similarly, the technological activities within the dimensions are organized according to their frequency, with the most frequent activity on the top row and the least frequent activity on the bottom row. For example, in the engineering dimension, the most frequent activity was structure building, and the least used activity was explaining basic functions.

Second, to analyze the nature of learning within the projects, we searched for curriculum-related learning areas (i.e., the interdisciplinary core entities, individual school subjects, and transversal competence themes) from the project plans and teachers' descriptions and reflections (Table 9.3). In the analysis, we named the learning areas with the terms used by the teachers in the data, resulting in a mixture of terms from the pre- and primary education curricula. The interdisciplinary core entities follow the naming of the pre-school curriculum, and the transdisciplinary competence themes follow the primary school curricula, which includes all seven themes (compared to six themes in the pre-school curriculum). In addition, one individual school subject, mathematics, was mentioned by both pre- and primary school teachers.

In the third phase of the analysis, we employed co-occurrence network analysis to detect and reveal underlying connections between objects (Sormunen et al., 2019; see also Moeller et al., 2017), here defined as relations between the learning areas and technological activities. The sub-categories from five technological dimensions (Table 9.2) and identified learning areas (Table 9.3) were set as two sets of

**Table 9.2** Technological dimensions and activities used within each dimension

| Crafting | Designing | Engineering | Documenting and sharing | Programming |
|---|---|---|---|---|
| Manual crafting | Sketching and drawing | Structure building | Child-centered documentation | Programming simple robotics |
| Digital producing | Observing design elements | Exploring electronics | Adult-oriented sharing | Computational thinking |
| | Digital designing | Exploring basic functions | Organizing final event | Programming games |
| | Molding | Investigating digital devices | | Observing programming |
| | Ideating | Explaining basic functions | | |

**Table 9.3** Learning areas based on the Finnish national pre- and primary education curricula (FNBE, 2016a, 2016b)

| Interdisciplinary core entities | Transversal competence themes |
|---|---|
| Diverse forms of expression | Thinking and learning to learn |
| Me and our community | Taking care of oneself and managing daily life |
| Exploring and interacting with my environment | Multiliteracy |
| I grow and develop | ICT competence |
| | Working life competence and entrepreneurship |
| School subject: mathematics | Participation, involvement and building a sustainable future |

keywords. The data were tabulated into three columns: project, technological activities and learning areas, which we investigated with the help of network visualization software tool VOSviewer (Waltman et al., 2010). The relatedness of items was determined based on the number of projects they occur in together, resulting in a network consisting of 24 keywords, with a minimum of 2 co-occurrences of a keyword. The keywords were mapped and clustered into three modularity-based clusters based on the occurrences and the link strength, resulting in the final network graph (Fig. 9.6).

In the following section, we first explore the technological dimensions implemented in the projects. Then we introduce three orientations to young students' STEAM education implemented through invention projects, each representing a different perspective to the approach.

## 9.5 Technological Dimensions in Pre-and Primary Schools' Invention Projects

The invention projects in the present study varied in nature, but they all included several creative technological activities, which represented all the five technological dimensions (Table 9.2). The dimensions—crafting, design, engineering, documenting and sharing, and programming—describe the diversity of digital and analog technological activities used in the processes. In what follows, we introduce the dimensions from the most frequently implemented to the least used dimension.

**Crafting** According to our analysis, the crafting dimension had substantial emphasis. It was implemented in all the projects except one (*Techno module*, which focused on programming), in several phases. Within this dimension, the children used various techniques and tools to create a final tangible or digital form to their technological ideas and solutions. They used art and craft supplies as well as recycled materials, such as packaging materials and parts from digital devices, to construct unique products. In addition, painting, printing, baking and other traditional art and craft techniques were used. Digital producing was conducted with 3D printers and 3D pens, vinyl cutters, and various applications that made sound or animation. Figure 9.1 illustrates the crafting process in the *Two Worlds* project, where the children constructed miniature worlds in cardboard boxes, creating meaning to their 3D-printed objects. In addition to using art and craft supplies, the children constructed circuits with electronic components, such as LED lights and small motors, to create functionalities in their miniature worlds.

**Designing** Designing and engineering dimensions were both equally important in the projects, and they were utilized almost as much as crafting. In designing, technology was used as either the object or the tool of design or both. The children designed their technological solutions, but they also used technological means to make their ideas visible. The dimension included traditional sketching, drawing, and molding activities, as illustrated in Fig. 9.2. The designs in the figure were produced in the *My neighborhood* project, where the children created elements for a stop motion animation about their neighborhood in 2050. The children designed their own characters, or "wanderers", and the various adventures these characters got into during the animation. In some projects, the children used digital tools, such as Tinkercad and Cookie Caster, for 3D designing, but these were not as frequent as the more traditional design activities. In addition to using various means to give visual form to their ideas, the children used digital photography for observing different design elements in their surroundings.

**Fig. 9.1** A miniature world from the *Two worlds* project with a 3D-printed "automatically" rising and lowering swimming tower and traffic lights guiding the jumpers. The child illustrated water with blue paper and white circles made of craft braids (Photo: Arto Vaahtokari)

**Fig. 9.2** Children's designs for the *My neighborhood* project. Molded "wanderers" with a storyboard for a stop motion animation (Photo: Kindergarten Myllynratas)

**Engineering** The most frequent activity within the engineering dimension was building various structures, such as beam, trellis, or arch structures with art and craft supplies or building blocks. The children also used simple technological tools to investigate basic functions, such as traction, pneumatics, and capillary action, and components to explore electronics by constructing circuits. Children are often naturally interested in these and include technological systems with engineering components in their play (cf. Stylianidou et al., 2018). For example, in the *Garden plot* project, the children investigated and tested water absorption by building various watering systems in their plantings with syringes, plastic straws and tubes, and old water bottles (Fig. 9.3). In some of the projects, the children were also encouraged to examine old digital devices by dissembling them and guided to explain their explorations within the engineering dimension.

**Documentation and sharing** The documentation and sharing dimension was implemented in most of the projects, and it included activities of both the children and the adults. They used technological tools to build the trail of their knowledge creation, enabling the reflection on what has been or should be learned (cf. Saarinen et al., 2019). The children documented the process by taking photos, making short videos, writing small texts, and using portfolio applications such as Seesaw. Figure 9.4 illustrates documentation by a child about his finished miniature world in the *Two worlds* project. The child has taken a photograph and explained his design with a small text, and the child's guardian has commented on the documentation. The adults supported reflection by encouraging the children to give each other feedback and documented the projects by writing weekly messages to guardians. Together, the children and the adults also organized exhibitions about their projects, inviting other groups from

**Fig. 9.3** A child explores absorption with a syringe and plastic straws for a watering system in the Garden plot project (Photo: Anneken Skaara)

the school or parents to visit. Some of the primary school groups participated in invention fairs, organized by our research group at the university, where the children presented their projects and explored the projects conducted in other schools.

**Programming** The least utilized dimension was programming, although programming activities have been found to be beneficial for developing basic cognitive functions (Papadakis et al., 2016). The dimension was implemented in six projects and included unplugged activities as well as testing, practicing, and playing with age-appropriate applications and early robotics. To learn the basics of computational thinking, the children practiced by "programming" a friend and playing with simple robotics, such as BlueBots, Lego WeDo, and Kubo. For example, in the *My neighborhood* project, the Kubo robot was programmed to move on a map of the preschool's surroundings (Fig. 9.5). In one group, Micro:bit microcontrollers were intended to use for measuring soil humidity. However, this proved to be too challenging for the children. Rather, they observed the coding conducted by adults and subsequently discussed the effects of the program with them.

The technological activities presented here represent all five technological dimensions. Although the teachers experimented invention pedagogy for the first time in practice, they thoroughly covered the process-oriented nature of working from design to engineering and crafting, and documenting, but the dimension of programming was still challenging to them.

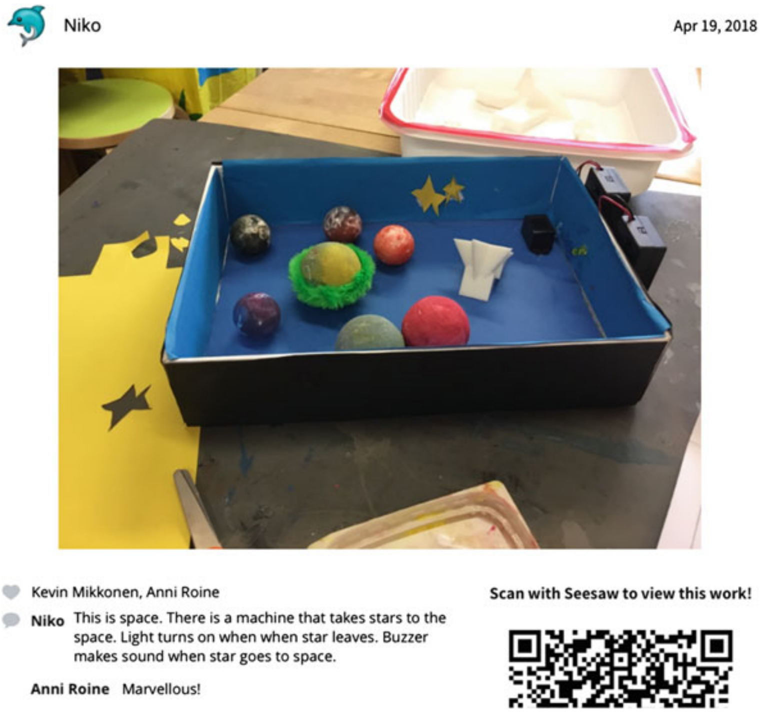


**Fig. 9.4** Child-centered documentation and sharing of the final artefact in SeeSaw application in the *Two worlds* project (note: all names are pseudonyms, and the texts are translated from Finnish). (Photo: Arto Vaahtokari)

## 9.6 Three Orientations in Young Students' STEAM Education

We were also interested in how the creative technological activities were related to the learning areas implemented in the projects (i.e., the interdisciplinary core entities, individual school subjects, and transversal competence themes). We conducted a co-occurrence network analysis to detect and reveal the underlying connections between the learning areas and the technological activities, which resulted in three clusters illustrating varying orientations: (1) The maker orientation, (2) the competence orientation, and (3) the digital orientation. The orientations and the connections are visualized in Fig. 9.6, where the red network represents the maker orientation, green the competence orientation, and blue the digital orientation. The bigger the dot and the more prominent the text, the more frequent the term was in the data. The thickness of the lines refers to the strength of the links between the keywords. In the network, some keywords have been shortened for the clarity of the illustration; the full keywords are presented in Table 9.4. Thus, in the following we interpret the figure and the table together.


**Fig. 9.5** The child is programming a Kubo robot in the *My neighborhood* project. The task was to program the robot back to the pre-school on a map of the preschool's surroundings (Photo: Kindergarten Myllynratas)

**Maker orientation** The maker orientation had the strongest emphasis in the projects. In Fig. 9.6, the red network includes many of the most relevant keywords (indicated with prominent text) and very strong links (indicated with thick lines) within the orientation and to other orientations as well. It included versatile technological activities and learning areas that represent various aspects of STEAM education. The maker orientation was the most interdisciplinary in nature, including the learning entities *Diverse forms of expression*, *Rich world of the language*, and *Exploring and interacting with my environment* as well as the school subject mathematics. Materiality and hands-on making were highlighted within the maker orientation, the technological activity *manual crafting* is in the center of the entire network and has many strong links all over the network. Significantly, one strong link connects manual crafting to *digital producing*, indicating that these two activities were implemented together many times. Naturally, manual crafting was also connected to design and engineering activities, such as *sketching and drawing* and *structure building*. However, the orientation did not include any documentation or sharing activities, suggesting that the evaluative and reflective phase of the process was not underlined alongside design and making. Neither did the orientation include any transversal competence themes. In sum, the focus of maker orientation was on interdisciplinary learning through a wide variety of hands-on design, engineering and crafting activities.

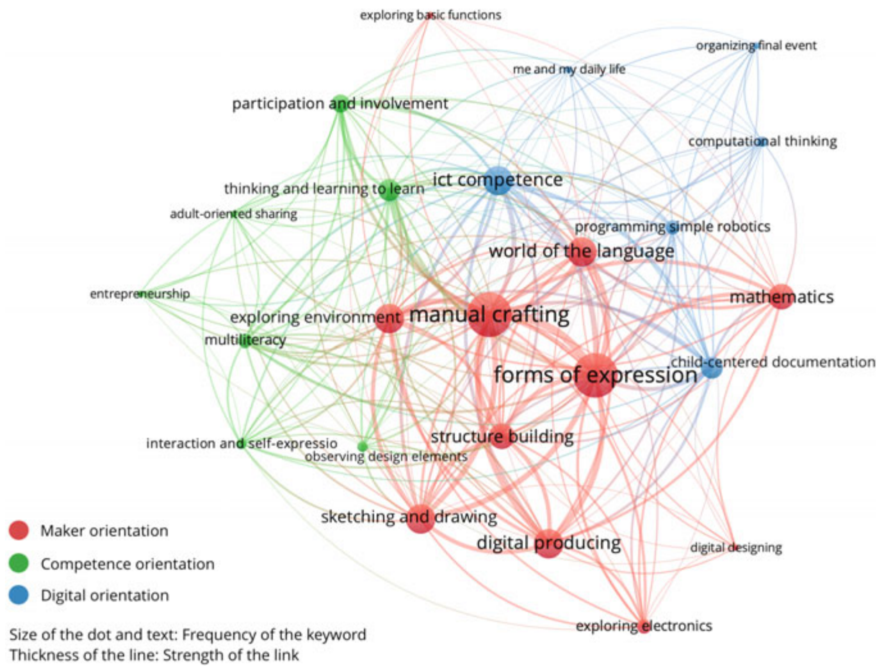


**Fig. 9.6** The three orientations network, based on the occurrences and the link strength of the learning areas and the technological activities of the projects

**Competence orientation** The competence orientation (green network) focused heavily on transversal competence themes; five of the seven themes were included in this orientation. The primary focal theme was *Thinking and learning to learn*, which is also connected to many other competence themes. Surprisingly, *Participation and involvement* is in the outskirts of the network, although this competence theme is underlined in many definitions of future-oriented learning, referring to co-agency with peers, teachers, parents, and communities (e.g., OECD, 2019). *Multiliteracy* is even less prominent in the network, albeit the projects included activities touching upon a variety of literacies (i.e., spoken and written language, numbers, digital data, and material artifacts). The technological activities implemented most within the competence orientation, *observing design elements* and *adult-oriented sharing*, were more cognitive in nature than in the maker orientation. In brief, the competence orientation emphasized the learning of general skills, and these are linked to "minds-on," rather than hands-on, activities.

**Digital orientation** The digital orientation (blue network) appeared to be the most narrowly focused of the three orientations, particularly in regard to the learning areas. This emphasizes *ICT competence*, which is one of the transversal competence themes. Only one other learning area, *Taking care of self and managing daily life* (cf. me and my daily life in Fig. 9.6), was included in this orientation. This

**Table 9.4** The three orientations, the included learning areas, and technological dimensions and activities

| Orientation | Learning areas | Technological dimensions and activities |
|---|---|---|
| Maker orientation | **Interdisciplinary core entities**<br>Diverse forms of expression<br>Exploring and interacting with my environment<br>Rich world of the language<br>**School subject**<br>Mathematics | **Designing**<br>Sketching and drawing<br>Digital designing<br>**Engineering**<br>Structure building<br>Exploring electronics<br>Exploring basic functions<br>**Crafting**<br>Manual crafting<br>Digital producing |
| Competence orientation | **Transversal competence themes**<br>Thinking and learning to learn<br>Participation and involvement<br>Multiliteracy<br>Cultural competence, interaction, and expression<br>Working life competence and entrepreneurship | **Designing**<br>Observing design elements<br>**Documentation and sharing**<br>Adult-oriented sharing |
| Digital orientation | **Transversal competence themes**<br>ICT competence<br>Taking care of self and managing daily life (Note. me and my daily life in Fig. 9.6) | **Programming**<br>Programming simple robotics<br>Computational thinking<br>**Documentation and sharing**<br>Child-centered documentation<br>Organizing final event |

learning area is quite peripheral in the network, indicating that ICT competence was seldom connected to children's everyday experiences, although digital technology is an important part in children's daily lives. These two competence themes were approached with programming activities, *programming simple robotics* and *computational thinking*, although these activities were used in less than half of the projects. Interestingly, the most prominent technological activity within the orientation was *child-centered documentation*. The children often used digital tools for documentation, so perhaps it was natural for the teachers to reflect that this activity was related to learning areas focusing on digital competence. Thus, the digital orientation emphasized the development of students' digital competence, but in a rather narrowly focused way.

The three orientations illustrate varying emphases on young students' STEAM education implemented through invention projects. In addition, they exemplify how introducing a new pedagogy is first linked to common practices and contexts and the more unfamiliar areas and activities are positioned in the outskirts of the orientation network, while also suggesting new directions for developing STEAM education further.

## 9.7 Discussion and Conclusion

The integrative STEAM approach has been argued to be useful for teaching and learning the twenty-first century competencies, but it has received little research interest, particularly in early education. Although some recent studies exist, the emphasis has mostly been on digital technology, providing a quite narrow perspective on technology education (e.g., Li et al., 2020). In the present chapter, we aimed to broaden this perspective by examining what kind of creative technological activities, both digital and analog, were used in pre-and primary school STEAM-oriented invention projects and how these activities were related to the learning areas pursued in the projects.

The projects included many technological activities, which represented all the five technological dimensions defined in our previous studies (Korhonen et al., 2020). Many of the activities were, in fact, common activities in young students' education, for example, building, manual crafting, and drawing. Nevertheless, analyzing them in relation to the technological dimensions revealed that simple and common activities can be used to support several aspects of students' technological competence (i.e., using, exploring, and creating technological solutions and tools) (cf. Fox-Turnbull, 2019; OECD, 2019). In addition to crafting and engineering activities, it was notable that design was a well-represented dimension. Previous research has found contradictory results regarding young students' designing, from children not being aware that they are following a plan (MacDonald et al., 2007) to a strong correlation between children's design intentions and their final products (Fleer, 2000). Therefore, children should be taught how to design, including the role and usefulness of drawing in developing design ideas (cf. Hope, 2005; Yliverronen, 2014). Design as a focal dimension in the invention process and pedagogy was underlined in our workshops for teachers, and the present results indicate that this dimension was further explored with the children. On the contrary, the programming dimension was not implemented as much as the other dimensions, although many programming tools were introduced in our workshops. This dimension is a new area to be covered in young students' education, and there are still challenges related to teachers' abilities to teach this area, to the lack of suitable learning materials, and also the possibilities of educational institutions to invest in age-appropriate programming tools (e.g., Kewalramani et al., 2020). In real classroom settings, the dimensions are naturally overlapping and entangled; for example, building structures with art and craft supplies represents both the engineering and the crafting dimension. However, acknowledging all the dimensions might help teachers to perceive the diversity and variety of technologies that can be used for creative learning activities, and they can also be used to map out children's existing, evolving, or desired technological competencies.

When analyzing the underlying connection between the technological activities and the learning areas pursued in the projects, three orientations emerged, each emphasizing varying elements of young students' STEAM education implemented through invention projects. The most prominent was the maker orientation, which was also the most interdisciplinary in nature and included more technological activities than the other orientations. As the name suggests, the orientation resembles maker-centered learning, which is generally seen as multidisciplinary, multimaterial, technology-enhanced, and comprehensive in terms of including all stages of creation, i.e. ideation, experimentation, making and reflection (e.g., Riikonen et al., 2020b). In many studies, maker-centered learning has been recognized as a strategic component of future-oriented education (e.g., Lundberg & Rasmussen, 2018); furthermore, it nurtures young students' academic identity (Hachey et al., 2021). The maker orientation also included many common activities for young students', but the less familiar activities were either in the outskirts of the network (digital designing and producing) or not at all included in the orientation (documentation and sharing, and programming dimensions). The maker-oriented approach to STEAM education might benefit from a more focused perspective, where less interdisciplinary and disciplinary learning areas are included, leaving room for transversal competence themes and more versatile technological dimensions.

Quite the opposite, the competence orientation included five transversal competence themes in total, but no interdisciplinary or disciplinary learning areas. The same is true in the digital orientation, with the exception that it included only two transversal competence themes. These two orientations included also documentation and sharing activities, indicating that these were linked with the themes (i.e., the evaluative and reflective dimension of technological activities corresponds to the development of transversal competence). The two orientations, however, included very few other technological activities. In particular, the digital orientation was quite narrowly focused on developing the students' digital competence with activities related to programming and documenting.

Nevertheless, our aim was not to judge the three orientations in terms of one being better than the other, but rather to illustrate the versatile ways of implementing the STEAM approach in pre- and primary students' invention projects. In addition, the orientations portray the broad scope of learning areas pursued in the projects. Our conclusion is that young students' STEAM education might benefit from a more focused, but not too limited, perspective, in which both interdisciplinary and transversal learning areas are included, while still leaving room for versatile technological dimensions including both digital and analog activities.

Like all research, this study has limitations that must be acknowledged. One lies in the nature of the data collected, which emphasizes teacher descriptions, reflections, and visual data. It was beyond the scope of this study to undertake a detailed analysis of the enacted children's and teachers' activities, which would have perhaps provided deeper insights into the nature of technological dimensions and learning areas implemented in the projects. Furthermore, a collective case study usually includes the same data sets from each case to make reliable cross-case generalizations and comparisons (Goddard, 2010). The data sets of the present study varied slightly from case to case due to the different research settings and projects; for example, some cases included teachers' written descriptions and reflections while others included transcribed teacher interviews. However, all the cases had similar contexts and participants, such as the nature of the projects implemented, and the same research objectives guided the analysis of each case. These limitations suggest avenues of future research on young students' STEAM education.

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## References

Bequette, J. W., & Bequette, M. (2012). A place for Art and Design education in the STEM conversation. *Art Education, 65*(2), 40–47.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (Vol. 1, pp. 17–66). Springer.

Daugherty, M. K. (2013). The prospect of an "A" in STEM education. *Journal of STEM Education: Innovations and Research, 14*(2), 10–15.

Fleer, M. (2000). Working technologically: Investigations into how young children design and make during technology education. *International Journal of Technology and Design Education, 10*(1), 43–59.

Fleer, M. (2011). Technologically constructed childhoods: Moving beyond a re-productive to a productive and critical view of curriculum development. *Australasian Journal of Early Childhood, 36*(1), 16–24.

Finnish National Agency of Education (FNAE). (2018). *National core curriculum for early childhood education and care 2018* (p. 3c). Finnish National Agency for Education, Regulations and Guidelines.

Finnish National Board for Education (FNBE). (2016a). *National core curriculum for basic education 2014* (p. 5). Finnish National Board for Education, Publications.

Finnish National Board for Education (FNBE). (2016b). *National core curriculum for pre-primary education 2014* (p. 6). Finnish National Board for Education, Publications.

Fox-Turnbull, W. (2019). Enhancing the learning of technology in early child-hood settings. *Australasian Journal of Early Childhood, 44*(1), 76–90.

Goddard, J. T. (2010). Collective case study. In A. J. Mills, G. Durepos, & E. Wiebe (Eds.), *Encyclopedia of Case Study Research* (pp. 163–165). Sage.

Hachey, A.C., An, S.A., & Golding, D.E. (2021). Nurturing kindergarteners' early STEM academic identity through makerspace pedagogy. *Early Childhood Education Journal* [published online].

Hatzigianni, M., Stevenson, M., Bower, M., Falloon, G., & Forbes, A. (2020). Children's views on making and designing. *European Early Childhood Education Research Journal, 28*(2), 286–300.

Hatzigianni, M., Stevenson, M., Falloon, G., Bower, M., & Forbes, A. (2021). Young children's design thinking skills in makerspaces. *International Journal of Child-Computer Interaction*, 27.

Hetland, L., Winner, E., Veenema, S., & Sheridan, K. M. (2013). *Studio thinking 2: The real benefits of visual arts education* (2nd ed.). Teachers College Press.

Hope, G. (2005). The types of drawings that young children produce in response to design tasks. *Design and Technology Education: An International Journal, 10*(1), 43–53.

Jones, A., Buntting, C., & de Vries, M. J. (2013). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*(2), 191–212.

Kalmpourtzis, G. (2019). Connecting game design with problem posing skills in early childhood. *British Journal of Educational Technology, 50*(2), 846–860.

Kewalramani, S., Palaiologou, I., & Dardanou, M. (2020). Children's engineering design thinking processes: The magic of the ROBOTS and the power of BLOCKS (electronics). *Eurasia Journal of Mathematics, Science and Technology Education, 16*(3).
Kilbrink, N., Bjurulf, V., Blomberg, I., Heidkamp, A., & Hollsten, A.-C. (2014). Learning specific content in technology education: Learning study as a collaborative method in Swedish preschool class using hands-on material. *International Journal of Technology and Design Education, 24*, 241–259.
Kokko, S., Kouhia, A., & Kangas, K. (2020). Finnish craft education in turbulence: Conflicting debates on the National Core Curriculum. *Techne Series—Research in Sloyd Education and Craft Science, 27*(1), 1–19.
Korhonen, T., Kangas, K., Riikonen, S., & Packalén, M. (2020). Teknologia oppimisen kohteena ja luovan toiminnan mahdollistajana [Learning technological and creative competencies]. In T. Korhonen & K. Kangas (Eds.), *Keksimisen pedagogiikka [Invention pedagogy]* (pp. 164–186). PS-kustannus.
Kumpulainen, K., & Sefton-Green, J. (2019). Multiliteracies and early years innovation. Perspectives from Finland and beyond. In *Routledge research in early childhood education.* Routledge.
Lavonen, J., Autio, O., & Meisalo, V. (2004). Creative and collaborative problem solving in technology education: A case study in primary school teacher education. *Journal of Technology Studies, 30*(2), 107–115.
Lavonen, L., Loukomies, A., Vartiainen, J., & Palojoki, P. (2021). Supporting pupils' scientific and engineering practices in everyday life contexts at the primary school level during a project-based learning unit in Finland. *Education*, 3–13.
Li, Y., Wang, K., Xio, Y. & Froyd, J. E. (2020). Research and trends in STEM education: a systematic review of journal publications. *International Journal of STEM Education, 7*(11).
Lindeman, K., Jabot, M., & Berkley, M. T. (2014). The role of STEM (or STEAM) in the early childhood setting. Learning across the early childhood curriculum. In *Advances in early education and day care* (pp. 95–114). Emerald Group Publishing Limited.
Lundberg, M., & Rasmussen, J. (2018). Foundational principles and practices to consider in assessing maker education. *Journal of Educational Technology, 14*(4), 1–12.
MacDonald, D., Gustafson, B. J., & Gentilini, S. (2007). Enhancing children's drawing in design technology planning and making. *Research in Science and Technological Education, 25*(1), 59–75.
Marsh, J. (2015). Researching technologies in children's worlds and futures. In A. Farrell, S. L. Kagan, & E. K. Tisdall (Eds.), *The SAGE handbook of early childhood research* (pp. 485–501). SAGE.
Moeller, J., Ivcevic, Z., Brackett, M. A., & White, A. E. (2017). Mixed emotions: Network analyses of intra-individual co-occurrences within and across situations. https://osf.io/b4cxt/
Organisation for Economic Co-operation and Development (OECD). (2019). *OECD learning compass 2030: A series of concept notes.* OECD.
Paavola, S., & Hakkarainen, K. (2014). Trialogical approach for knowledge creation. In S.-C. Tan, H.-J. Jo, & J. Yoe (Eds.), *Knowledge creation in education* (pp. 53–72). Springer.
Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016). Developing fundamental programming concepts and computational thinking with ScratchJr in pre-school education: A case study. *International Journal of Mobile Learning and Organisation, 10*(3), 187–202.
Papavlasopoulou, S., Giannakos, M. N., & Jaccheri, L. (2017). Empirical studies on the maker movement, a promising approach to learning: A literature review. *Entertainment Computing, 18*, 57–78.
Pöllänen, S. (2009). Contextualising craft: Pedagogical models for craft education. *International Journal of Art and Design Education, 28*(3), 249–260.
Quinn, H., & Bell, P. (2013). How designing, making, and playing relate to the learning goals of K–12 science education. In M. Honey & D. Kanter (Eds.), *Design, make, play: growing the next generation of STEM innovators* (pp. 17–33). Routledge.

Riikonen, S., Kangas, K., Kokko, S., Korhonen, T., Hakkarainen, K., & Seitamaa-Hakkarainen, P. (2020a). The development of pedagogical infrastructures in three cycles of maker-centered learning projects. *Design and Technology Education: An International Journal, 25*(2), 29–49.

Riikonen, S., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2020b). Bringing maker practices to school: Tracing discursive and materially mediated aspects of student teams' collaborative making processes. *International Journal of Computer-Supported Collaborative Learning, 15*(3), 319–349.

Saarinen, A., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2019). Building student-centric ePortfolios in practice: Areas of documentation in a craft learning activity. *Techne Series—Research in Sloyd Education and Craft Science A, 26*(2), 16–28.

Seitamaa-Hakkarainen, P., Viilo, M., & Hakkarainen, K. (2010). Learning by collaborative designing: Technology-enhanced knowledge practices. *International Journal of Technology and Design Education, 20*(2), 109–136.

Slutsky, R., & DeShetler, L. M. (2017). How technology is transforming the ways in which children play. *Early Child Development and Care, 187*(7), 1138–1146.

Sormunen, K., Juuti, K., & Lavonen, J. (2020). Maker-centered project-based learning in inclusive classes: supporting students' active participation with teacher-directed reflective discussions. *International Journal of Science and Mathematics Education, 18*, 691–712.

Sormunen, K., Lavonen, J., & Juuti, K. (2019). Overcoming learning difficulties with smartphones in an inclusive primary science class. *Journal of Education and Learning, 8*(3), 21–34.

Stake, R. (2005). Qualitative case studies. In N. Denzin & Y. Lincoln. (Eds.), *The SAGE handbook of qualitative research* (3rd ed.) (pp. 443–466). Sage.

Stylianidou, F., Glauert, E., Rossis, D., Compton, A., Cremin, T., Craft, A., & Havu-Nuutinen, S. (2018). Fostering Inquiry and Creativity in Early Years STEM Education: Policy Recommendations from the Creative Little Scientists Project. *European Journal of STEM Education, 3*(3), 15.

Sundqvist, P., & Nilsson, T. (2018). Technology education in preschool: Providing opportunities for children to use artifacts and to create. *International Journal of Technology and Design Education, 28*(1), 29–51.

Turja, L., Endepohls-Ulpe, M., & Chatoney, M. (2009). A conceptual framework for developing the curriculum and delivery of technology education in early childhood. *International Journal of Technology and Design Education, 19*, 353–365.

Waltman, L., Van Eck, N. J., & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics, 4*(4), 629–635.

Yliverronen, V. (2014). From story to product: Pre-schoolers' designing and making processes in a holistic craft context. *Design and Technology Education: An International Journal, 19*(2), 8–16.

# Chapter 10
# Virtual Learning Environment to Strengthen STEM Competencies in Preschool Children

**Anabelem Soberanes-Martín**

**Abstract** Intervention programs in early childhood education are aimed at cognitive, physical, linguistic, and socioemotional development, which can be strengthened with the incorporation of technological resources, so the objective was to develop a virtual learning environment; the first stage includes aspects that strengthen the areas of Science, Technology, Engineering, and Mathematics (STEM) and present the information of reinforcement and integration of exercises to identify the elements they observe in nature, strengthen their fine and gross motor skills, design things with different materials and solve problems through counting. Three stages are identified (i) General aspects, the study participants were selected, the competencies and cognitive process, topics to be addressed, the materials to be developed, the instruments to be applied were selected to determine the quality of the application, (ii) The virtual learning environment is composed of four sections: tutors, students, teachers, and an application for mobile devices that includes augmented reality resources, (iii) Functionality and usability testing. The results are encouraging to verify the premise of contributing to the education of children from 3 to 6 years of age in the eastern zone of Mexico.

**Keywords** Pre-school education · Initial training · Educational technology

## 10.1 Introduction

The premise of the European pillar of social rights mentions that children have the right to an education with affordable and good quality early childhood care (Education, Audiovisual and Culture Executive Agency [EACEA], 2019). aspect that is present in educational institutions in several countries (Driessen, 2018; OECD, 2018) offer a combination of play and learning activities aimed at preparing infants, in a first moment to stimulate the socioemotional and cognitive development of

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children, and in a second moment for them to learn to read, write and count. It can be in different scenarios, full-time, part-time, public, or private institutions. However, what is sought is to contribute to environments that lack educational stimulation in the family or socioeconomically disadvantaged environment, as is the case of the context where this proposal is developed.

Dillon et al. (2017) mention that science can influence children's cognitive development in stages from 4 to 9 years old, mainly in mathematical thinking. Nevertheless, it is also essential to have capable and prepared teachers (United Nations Children's Fund, 2019; Driessen, 2018; EACEA, 2019) to address each child's condition. Although in other countries as Colombia and Mexico, it is noted that there are proposals for programs and projects to encourage science in early education and there is a significant investment, the approach to science in the classroom has not been seen (Ortiz & Cervantes, 2015).

A virtual learning environment (VLE) includes tools, documents, and any other means that support students, tutors, and teachers in early education through an interdisciplinary approach that allows supporting students' learning by considering real-world situations.

The teacher is a guide in the teaching-learning process; however, in a society with constant changes, teachers must promote the use of technologies for a favorable change in education; the use of Information Technologies in the educational system favors students' learning, allows them to expand and develop skills that allow their insertion into the knowledge society.

This chapter presents a virtual learning environment (VLE) called NekuKids, which incorporates technology to strengthen STEM competencies in children from 3 to 6 years old; a review of the context of early childhood education is made, up to preschool environments to achieve the incorporation of technology resources through a VLE; the integration of video games in early education, which shares the characteristics of most preschool institutions, is exposed. Also, the four main sections of NekuKids are described: (1) Students, (2) Teachers, (3) Tutors and (4) a mobile application (video game) to exercise some concepts and train executive functions, it is supported by what is expressed by Papadakis and Kalogiannakis (2017) who point out that young children explore and learn with mobile devices in ways that are natural for them (touch, repetition, trial, and error).

The objective was to build a virtual learning environment for children in early education, two levels for each of the subjects (STEM); activities were designed considering the learning-by-doing approach, in addition, to integrate the four c's (creativity, collaboration, critical thinking and communication). The VLE was developed in the eastern zone of the State of Mexico, Mexico; where Spanish is spoken, another skill that is reinforced with NekuKids is English as a second language.

## 10.2 Background

There are several strategies to support the development of children at an early age; the topics of early childhood education were analyzed, aspects that support the development of the virtual learning environment were reviewed, and video games were also examined.

### *10.2.1 Early Childhood Education (ECE)*

Early childhood education is paramount; therefore, governments of various countries consider educational reforms as such as those exposed by Bertram and Pascal (2016) making a comparative of the policies of education systems in Chile, Czech Republic, Denmark, Estonia, Italy, Poland, Russia, and the United States, on public policies that governments acquire in educational matters and how they participate in the development, noting that the primary basis is to invest and find new ways of future research to progress the child educational field jointly, which is ratified by some authors (Phillips et al., 2017; Zubairi & Rose, 2017) and the United Nations Children's Fund (2019). This incites other countries to establish early childhood education as a priority topic of investing.

Studies are identified that expose progress on the issue; for example, EACEA (2019) states that 95% of students in the range of 4–6 years old receive the appropriate education at their level across Europe. However, it highlights that not all European countries have the conditions to educate children under three years old; there is not suitable material for all the little ones. Furthermore, he points out that the scope of European regulations for children's institutions is based on four characteristics: structural organization, governance, staffing requirements, and educational content. Similarly, Phillips et al. (2017) express that in the United States, preschool education is being adequate and functional according to the new challenges.

However, not in all countries, is presented in the same way. United Nations Children's Fund (2019) describes the progress of some low-income countries in the field of education: Mongolia, Nepal, Nigeria, Ethiopia; the study emphasizes the importance of education from early childhood because during the first years of life children develop 85% of their brain capacity. Quality early childhood education generates a positive sequence of learning, while lack of access to it restricts opportunities in their development. Driessen (2018) expresses that early childhood education programs in the Netherlands sometimes present educational disadvantages for the little ones who do not have support from their families towards education or economic deprivation of some sectors of the population. To support such a situation, Zubairi and Rose (2017) highlight that it is required in many cases not to skimp on early education and invest everything necessary in strengthening this educational area. Something considerable to highlight is the educational gaps that depend too much on the economic condition of the communities. To achieve it, some strategies have been proposed with a home-based program that focuses on parents, and another program is school based (Driessen, 2018).

Other attempts to combat educational disadvantage focus on preschool and early elementary years, emphasizing linguistic and cognitive development (Driessen, 2018). Zubairi and Rose (2017) present three case studies in Jamaica, South Korea, and Tanzania. They mention that for the full development of children, health, protection, nutrition, and early learning is required; if some aspect is missing, kids are at risk for their growth.

### *10.2.2 Preschool Environments and Infant Education*

According to research, children attending preschool education have greater chances to develop socially; it was recommended that play and learning environments be outdoors (The Natural Learning Initiative, 2018; Shaari & Ahmad, 2016; Cheptoo, Violet & Syomwene, 2018; OECD, 2018). However, there are no regulations in this regard; that is, the importance of the physical environment of preschool cannot be ignored in México. Providing a quality and properly designed physical environment will boost children's development and education.

Learning environments such as space, layout, classroom display, among others, are vital to improving children's achievement in early instruction; Skinner's theory of behaviorism argued that environmental factors govern language development, contributing to better school readiness among children and a better educational system.

Education in the first years of life is a continuous and integral process, a product of multiple experiences that the school provides to children, through interaction with society and the environment, being the basis of the integral formation of the human being. Some of the many pedagogical tools or strategies are games, performing arts, painting, and reading, which are transformed into ludic-pedagogical strategies that favor the child's integral development (Cortés & García, 2017).

In addition, some authors mention that it is required that from an early age children show interest in science so that they are directed to the world of research; this can be achieved through curiosity since the desire to know and learn is excellent in children; hence our proposal to develop a virtual learning environment. Regarding the incorporation of science in early childhood education, Ortiz and Cervantes (2015) see it as something foreign that is contemplated in the curricula, but its development is not as expected.

Cortés and García (2017) talk about various strategies that teachers can implement so that children between 0 and 6 years of age can acquire the foundations of knowledge. The first strategy he mentions is the game; since children find their personality in this age of development, various games can be organized by teachers to generate in children motivation, exploration, learning, problem-solving, thinking skills, among other aspects. Another strategy that can be used is the environment because children like to be in constant contact with what nature offers; in addition, there are resources that teachers can use ideally for teaching, to mention a few: plastic arts, reading, technology, music, dance, singing and other dynamics such as the use of puppets, There are also other factors in the education of children, including the environment, the age of the children, the teaching staff, the size and organization of the classroom (Noor, 2021). Papadakis et al. (2018) emphasize that motor skills such as coordination of children of this age should be considered; they are still developing and generally cannot handle prolonged periods of demanding work.

Hence, the importance of play and its role in the learning process, focusing on play with reference to cognitive, social, and physical needs. The role of play is central to the learning process in early childhood education settings. Play provides a platform through which children can learn about themselves and the world around them by interacting with it.

### *10.2.3 Incorporation of Video Games in Early Childhood Education*

Games in education can be seen as interfering with learning. However, their role in education is to increase students' motivation and engagement, enhance visual skills, improve interaction and collaboration skills with peers, and apply game values in the real world. Some studies (Kokkalia et al., 2017; Heins, 2017; Fahad, 2017; Zirawaga, Olusanya & Maduku, 2017, Idárraga et al., 2017) mention that video games can provide insights into how young children learn while playing, achieve better literature, cognitive skills, mathematical, motor, and communication skills with the support of games and new technology. On the other hand, children facing learning and developmental difficulties can develop better coping strategies.

In addition, the video games are a tool that generates motivation and interest in children, which allows the development of cognitive and motor skills, it increases cooperative work skills, improving social relations; so, with a good direction, video games can be implemented as a tool to optimize teaching processes (Idárraga et al., 2017). An essential premise is that educational games have demonstrated students increased socioemotional skills, critical reasoning, and teamwork. With this, the motivational role of gamification in early childhood in the classroom can be identified (Giménez et al., 2021). Mental images are associated with emotions through consciousness addictive behaviors can be adopted, online games affect the physical behavior of the individual, the user's interest is divided into two: actions of the player and behavior, which is related to a group whose objective is to socialize with other participants ( Zhai et al., 2021).

The video game industry relies on the flow theory to generate an immersive experience to the extent of producing disconnection from the real world; this is achieved through the following points: rewards, exposing goals that translate into progress, feedback, promoting deep concentration, and managing the balance between the challenge and the player's skill (Marín-Navarrete, 2020). In addition, we should consider the persuasive design that employs psychological and social theories to influence human behavior, through Fogg's model, which considers that the willingness to adopt a new behavior depends on motivation, the ease to perform it, and a signal of its execution, in case of the absence of the motivator will cause the person to ignore it and will not adopt new styles (Sebastian et al., 2017).

There is still the dilemma of using video games in education, especially in preschool children. Research suggests that games can be used effectively in the school classroom, considering the subject curriculum to support their formation and knowledge acquisition (Kokkalia et al., 2017). If school is to be made more engaging and relevant to real life, it is necessary to give children more appropriate skills. Fogg's model of human behavior where the causes that produce a behavior change are studied, which are: the trigger is an action that brings about the change, the ability is associated with the capabilities to perform the activity, and the motivation represents the willingness to participate (Aranda & Caldera, 2018). This approach is appropriate if one seeks to change behaviors through gamification (González, 2019).

Finally, the methods of implementing integrative pedagogical activities for children in early childhood education and care through games are a tool for e-learning that impacts society and enhances gamification in the learning of infants (Guerrero, 2018; Sampedro et al., 2016).

## 10.3 Method

To achieve the objective, the research design was carried out.

### *10.3.1 Characteristics of the Participants*

An invitation was sent to 25 public and private preschool institutions in the eastern zone of the State of Mexico, Mexico, of which 12 agreed to participate, then teachers were called, and all agreed to collaborate (15); the parents of the children were invited, initially, 10 students per group participated, but due to the covid-19 pandemic, the validation of the VLE was carried out with 22 children with their guardian.

There were 59 participants in the research, distributed in three categories:

Students interested in participating and testing the environment, their role is to perform the activities hosted in the virtual environment and review lessons. Table 10.1 shows the descriptive data of the 22 students. The mean age of the students in the sample is 4.09 years.

Teachers involved in the development of the EVL are ten preschool teachers and five elementary school teachers; they oversee preparing lessons that students must review to support their learning process, generate guides, and support material. Table 10.2 shows the descriptive data of the 15 teachers. Some of their characteristics are personnel with 5 to 10 years of experience in early childhood education.

**Table 10.1** Descriptive indicators of the participating students

| Age | | Gender | | Frequency | Percentage |
|---|---|---|---|---|---|
| | | Female | Male | | |
| | 3–4 | 8 | 5 | 13 | 54.55 |
| | 5–6 | 5 | 4 | 9 | 45.45 |
| | Total | 13 | 9 | 22 | 100.00 |
| Type of institution | | Gender | | Frequency | Percentage |
| | | Female | Male | | |
| | Private | 9 | 6 | 15 | 68.18 |
| | Public | 4 | 3 | 7 | 31.82 |
| | Total | 13 | 9 | 22 | 100.00 |

**Table 10.2** Descriptive indicators of the participating teachers

| Age | Gender | | | Percentage |
|---|---|---|---|---|
| | Female | Male | Frequency | |
| < 25 | 1 | 0 | 1 | 6.67 |
| 25–30 | 1 | 1 | 2 | 13.33 |
| 31–35 | 7 | 2 | 9 | 60.00 |
| 35< | 2 | 1 | 3 | 20.00 |
| Total | 11 | 4 | 15 | 100.00 |
| Years of Experience | Gender Female | | | Percentage |
| | | Male | Frequency | |
| <5 | 3 | 1 | 4 | 26.67 |
| 5–10 | 6 | 2 | 8 | 53.33 |
| +10 | 2 | 1 | 3 | 20.00 |
| Total | 11 | 4 | 15 | 100.00 |
| Type of institution | Gender | | | Percentage |
| | Female | Male | Frequency | |
| Private | 9 | 3 | 12 | 80.00 |
| Public | 2 | 1 | 3 | 20.00 |
| Total | 11 | 4 | 15 | 100.00 |

Tutors can be the father, mother, or other people responsible for the student; their function is to supervise the activities carried out by the student and to support the learning process. Table 10.3 shows the descriptive data of the 22 tutors, the participants in this section are directly related to the number of students. The average age was 27 years old.

The data were obtained in an objective manner, the use of the information and images presented was carried out under ethical guidelines; the researcher had the

**Table 10.3** Descriptive indicators of the participating tutors

| Age | Gender | | Frequency | Percentage |
|---|---|---|---|---|
| | Female | Male | | |
| <25 | 2 | 1 | 3 | 13.64 |
| 25–30 | 8 | 4 | 12 | 54.54 |
| 31–35 | 3 | 1 | 4 | 18.18 |
| 35< | 2 | 1 | 3 | 13.64 |
| Total | 15 | 7 | 22 | 100.00 |
| Type of institution | Gender | | Frequency | Percentage |
| | Female | Male | | |
| Private | 11 | 4 | 15 | 68.18 |
| Public | 4 | 3 | 7 | 31.82 |
| Total | 15 | 7 | 22 | 100.00 |

moral responsibility to respect, value, and always make intentional use of the participants' contributions. Participants were fully informed about the purpose and process of the research. Teachers and tutors were then asked to sign informed consent letters in which they accepted and were authorized to be part of the research. Likewise, the author declares that there is no conflict of economic or personal interests in known competing relationships that could have influenced the work reported in this document. At all times the information was treated and presented with integrity, to avoid, as mentioned by Petousi and Sifaki (2020), falling into misconduct in the research in any of the individual, organizational or structural sectors, leading to fraud, fabrication, falsification, or plagiarism of the information presented.

### *10.3.2 Data Collection Tools*

The two instruments were answered with the support of the teacher or parents, considering the infant's learning or perception.

*Instrument* 1, composed of 10 questions-activities on the four STEM areas per level; in the pre-test, the students could get it right, wrong, or not answer. After interacting with NekuKids, the same instrument was applied, now called post-test.

*Instrument* 2, the usability was validated with the support of the people involved in manipulating the virtual environment; it was verified that the interface is intuitive and easy to use, the colors do not tire the eyes. A performance test was also performed, which consisted of five children manipulating the environment; the intention was to measure the speed of processing and response.

*Instrument* 3, the virtual learning environment was evaluated by applying the template for the analysis of a platform proposed by Domingo (2019), which consists of 56 items distributed in three sections:

1. Pedagogical characteristics, divided into teaching strategies, content and materials, and evaluation.
2. Organizational characteristics, with a section on access and distribution of academic information, communication space, human and technical support, and institutional aspects.
3. Technological characteristics, with a review of usability, orientation, and navigation by users.

### *10.3.3 Procedure*

It began with the systematic review of early childhood education, learning platforms, executive functions, generic skills, and learning styles in early childhood (3 to 6 years old); the documentary research allowed analysis to design the platform to stimulate learning in children, analytical methods capable of awakening visual memory are incorporated; they go from the general to the particular and emphasize visual, auditory, and kinesthetic channels to stimulate the understanding of STEM subjects. The develop of VLE is divided into three stages.

(1) **Pre-production** refers to determining the requirements for the learning environment; five aspects were considered:

- *Selection of executive functions,* determining the learning objective, and satisfying the stated need, the in-depth interview can obtain the information. At this stage, 15 early education teachers were approached, and they commented that it is easier to capture children's attention through images, games, and songs.
- *Content selection of the course distributed in blocks*; in addition, the levels of knowledge advancement of the subject can be selected; they can be essential, intermediate, and advanced; the profile of the users was detailed. It helps determine the most appropriate medium to transmit each content, determine the appropriate communication means to transfer the information and define the teaching modality based on psychological and pedagogical theories and specific technological resources. Thus, the proposal of Soberanes-Martín et al. (2020) was taken up again to develop a VLE called NekuKids to address the subjectivity of a problem, identifying roles and actors (teacher, tutor, children, school infrastructure, experts), as well as integrating different types and degrees of exercises.
- *The instructional design develops the didactic guide*, which contains identification data, objectives, competencies (conceptual, attitudinal, and procedural), contents, products, resources, evaluation, and references.
- *Outline and final design,* the content and presentation of the product is preliminarily structured, and it is necessary to follow a series of stages such as outline,

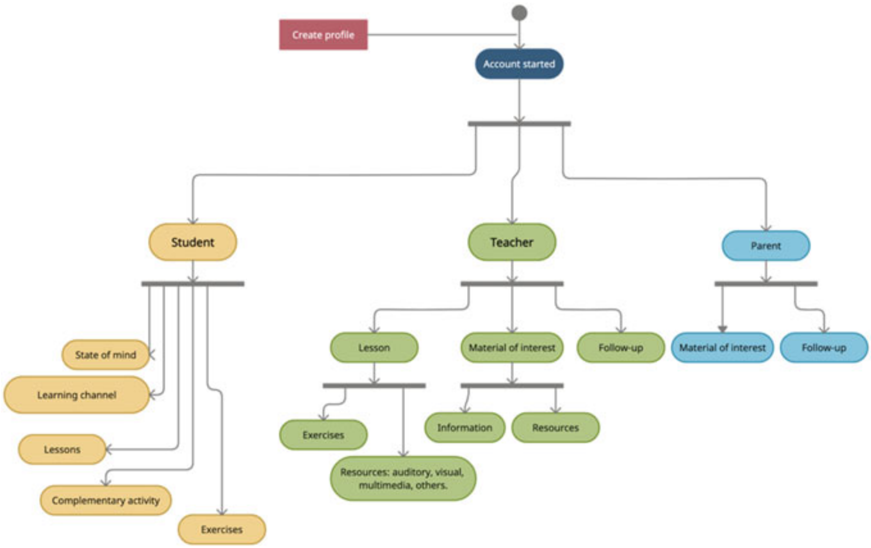


**Fig. 10.1** Wireframe of interfaces

standards, and final design. A Wireframe of interfaces can be used as a guide for the design of the screens (see Fig. 10.1), where it is specified, which aspects can be performed by each user who will use the learning environment.

- *Design and selection of evaluation instruments:* tools are created or identified to evaluate the effectiveness of the environment, considering opinions, learning, transfer, and results.

Once the VLE's logical and visual design stage has been completed, we proceed to production.

(2) **Production** refers to the stage in which five aspects are integrated:

- *Elaboration and selection of materials* for each block, the resources vary depending on the type of learning; they can be videos, audios, or documents. The development of learning objects involved five specific design tasks: content, architectural, navigation, aesthetic, and interface. Materials and videos were created for each block, which serves as an introductory module; its objective is to provide the student with fundamental knowledge. Another aspect considered for the development of the VLE was the flow theory proposed by Mihaly Csikszentmihalyi that describes the behavior at the time of performing some activity which analyzes certain factors such as the reduction of anxiety, boredom, space, and time of concentration, as well as the observation capacity (Mangieri, 2017).
- *Development of the learning community*, programming of the VLE, selecting the programming language, database manager, design of forms, fields to be stored, coding of interfaces, and linking the application with the database.

- *Validation of the activities* according to the learning objectives must be verified that the activities carried out in the VLE are in line with what was proposed at the beginning of the learning process.
- *Pilot test* to verify that what has been developed meets the objectives, testing with users with similar characteristics to the end-users and performed under natural conditions.
- *Functional testing*, that the learning environment works as desired to meet the objective for which it was developed, that the corresponding screens are displayed, reports the detected failures for correction, to deliver a stable environment.

(3) **Post-production,** actions carried out for the implementation of the VLE.

- *Dissemination of the VLE and training of users*, the environment must be made known so that it begins to be known and used by the recipients. It is convenient to take care of the process, and emphasis is placed on training. To avoid it being the reason it is not used, it can be using courses, manuals, or tutorials.
- *Online community* must be installed in the server where it will be used so that the database and the necessary resources for its operation are configured.
- *Application of usability and acceptance metrics,* previously elaborated metrics can be used or adapted to the environment's needs.
- *Analysis of feedback* and tools on the learning community, oriented to allow the student to permanently reflect on each action or activity he/she develops.
- *Monitoring and maintenance of the VLE*, it is necessary to continue verifying the operation of the environment for possible unforeseen events, maintenance of the environment, if necessary, programmed backup of information, downloading, and debugging of groups.

Descriptive research was used, the results obtained during the tests to evaluate the performance and performance of children using the application are exposed. Figure 10.2 represents the outline of the phases mentioned; it is not a recipe as such. However, this procedure can be a guide for the development of virtual learning environments.

## 10.4 Results

The results are presented in two sections: (i) Description of the NekuKids learning environments, and (ii) the results of the instruments applied during the implementation of the virtual learning environment.

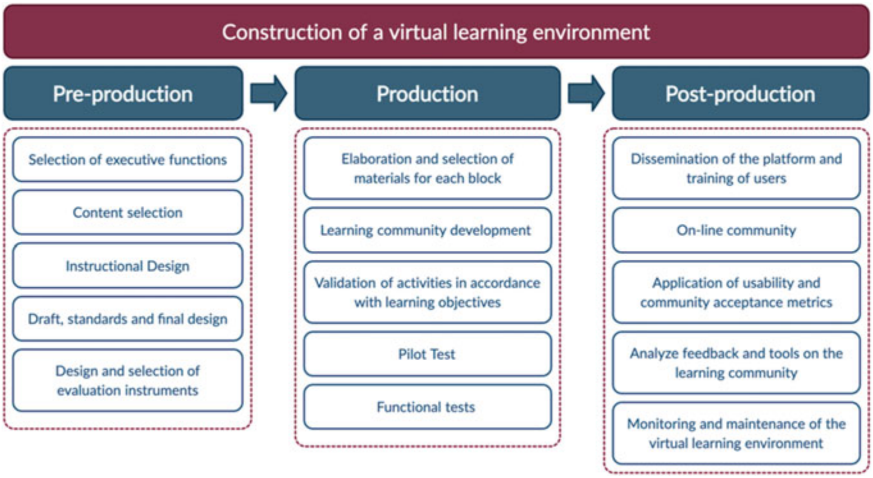


**Fig. 10.2** Scheme of the process for the creation of a VLE

### *10.4.1 NekuKids Learning Environment*

The learning environment is called NekuKids, whose origin comes from the words Nekutilistli which means knowledge in Nahuatl (Yuto-Nahua macrolanguage spoken in Mexico and Guatemala), and kids (children). The image representing the application is an axolotl (an amphibian species from the basin of Mexico) represented in different situations according to the topic in question, using colors that are attractive to infants.

The main page (see Fig. 10.3) includes a button at the top to enter the VLE. In the beginning, there is a form that the user must fill in to register for the first and only time; when entering, a screen is displayed where the user must choose the type of user: teacher, student, or tutor (Fig. 10.4).

Once registered, the corresponding section is displayed; the virtual learning environment is composed of four sections: tutors, students, teachers, and an application for mobile devices, which are described below:

(1) Considering the student profile, a screen appears where you must select an image that corresponds to your mood. Next, a page appears showing three images related to the way you prefer to learn (see Fig. 10.5), then exercises are displayed according to the channel that corresponds to you. Finally, the activity appears to check the topic to be completed; the scores are stored to keep track of the child's progress. The student's result is evaluated by the VLE, can also be reviewed by the teacher, and consulted by the tutor; the virtual environment allows downloading to mobile devices.

(2) The teacher section has three options: Lessons (exercises and resources of the subject), the material of interest, and student follow-up; the teacher can store exercises that the tutor can later use for the little ones to review, elaborate

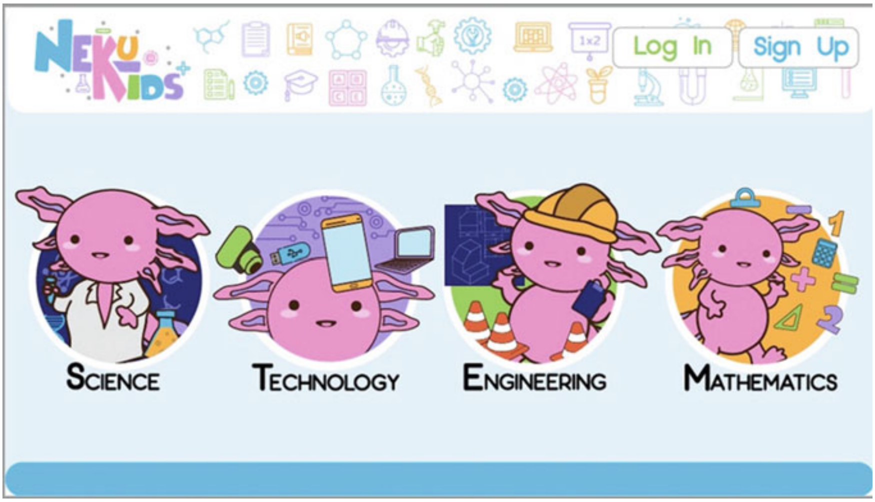


**Fig. 10.3** Home page

activities for the child to solve them and follow up on the progress they have made; the option host exercises, allows the teacher to share lessons that the child should review; multimedia, shows educational videos to support the child in their learning; the material of interest is focused on the tutor, the information that is shared is regarding the care, rights, and norms established by educational authorities during the education of the little ones. The multimedia section allows the teacher to store educational videos for the child to watch and review the lessons.

(3) The tutor section has two options: The material of interest option allows storing leaflets, brochures, or any relevant information to the tutors. The stored information offers the tutor advice to support their child during the learning process and care offered to the child to improve their school performance. In addition, the student tracking section shows the progress of the child. To view a student's progress, click on the history option. A progress screen is displayed, presented by the subject; each module has lessons that the student must review and answer an activity or exercise to evaluate the progress obtained in that section.

(4) Application for mobile devices version 1.0 is a functional prototype. It consists of three sections, mathematics that allow from associating numbers with objects and basic operations; in the area of science it is requested activities that have been presented with Lego Digital Designer, from assembling some basic figures by color, shape or number of pieces, among others; experiments in natural sciences, the level must be selected (in this phase are two), then you must choose the activity to start, the description is displayed, or you can listen, the requested action is performed and allows to continue with the following training

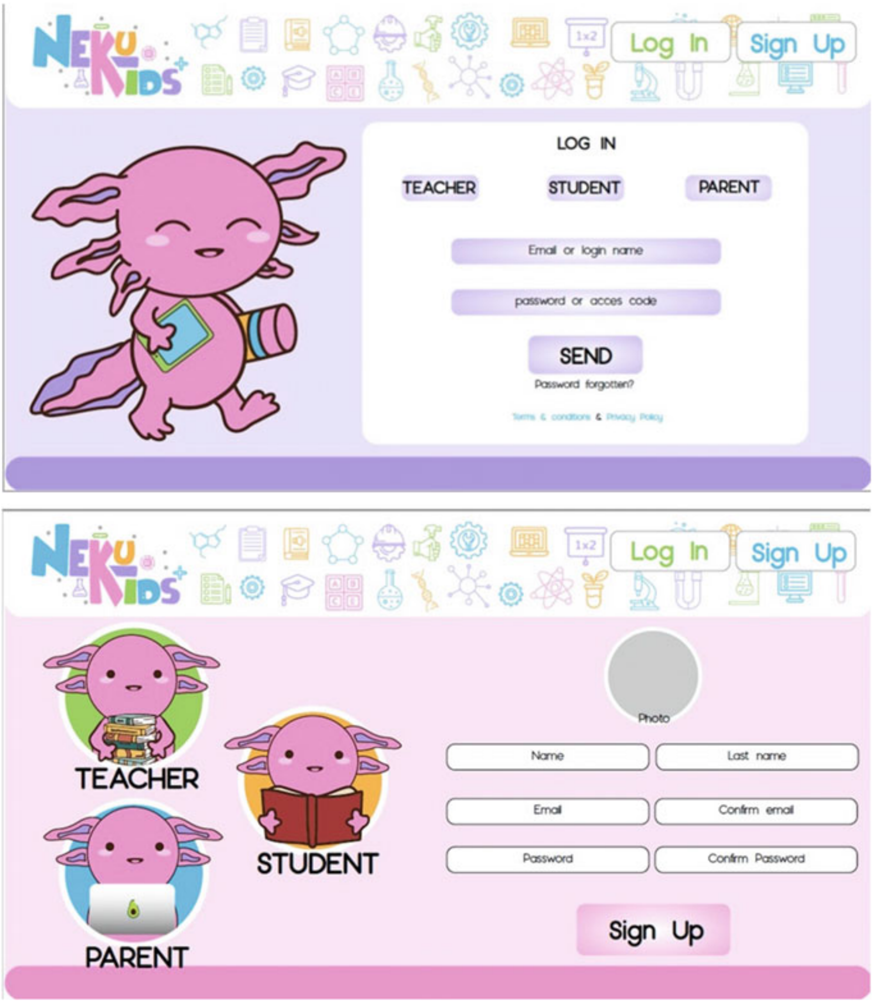


**Fig. 10.4** Login page and User registration page

or continue at another time, some elements of gamification were considered in its development. In addition, they have incorporated some augmented reality resources in some sections that allow children to manipulate the objects presented. Figure 10.6 schematizes the general operation of NekuKids.

In Table 10.4, the indicative NekuKids STEM learning activities with their corresponding objectives to be developed are indicated.


**Fig. 10.5** Identification page of the student's state of mind and Page to select the learning channel

### *10.4.2 Testing of the Virtual Learning Environment and Mobile Application*

Results of the two instruments:

***Instrument*** 1, in the pre-test, the students got 47% right, missed 49%, and did not answer 4%; in the post-test (after using NekuKids), they answered correctly 94%, missed 5%, and did not answer 1%.

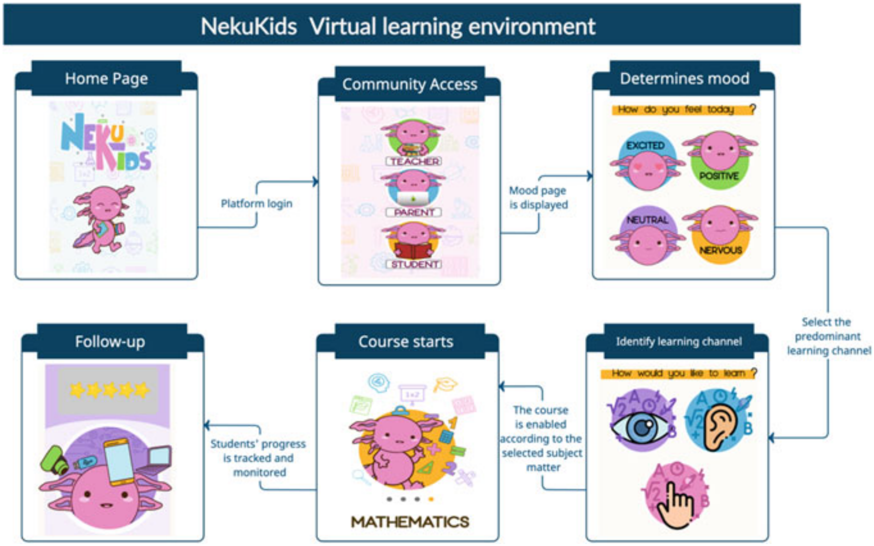


**Fig. 10.6** General operation of NekuKids

***Instrument*** 2, usability, was carried out with the support of the people involved in the manipulation of the virtual environment, for the evaluation of the virtual environment consisted of functionality, the 15 teachers manipulated it to verify that the buttons perform the corresponding activity, that the flow in the execution is correct, that is, that the sequence is not lost due to coding errors; the coding of the environment was carried out by modules that were later integrated and their overall functioning was validated using the integration test, for which the support of the teachers who verified the functioning of the teacher module and twelve parents who manipulated the tutor section was requested, in addition, it was verified that the interface was intuitive and easy to use, and that the colors used were not tiring to the eye; the performance test consisted of five children manipulating the student section, the intention was to measure the speed of processing and response, as well as the assessment of ease of use, the colors used, graphics and hyperlinks were evaluated; the interface test allowed to count the number of clicks that the child must give to perform a specific function. After the test and with the results obtained, it was determined to make some changes; among them, a color was selected for the interfaces by type of user (yellow for students, blue for tutors, and green for teachers). In addition, considering that the children do not yet know how to read, listening to directions was added to support them during the process. The results obtained are encouraging about the process of building a virtual learning environment.

**Table 10.4** Description of objectives and activities by NekuKids area

| Area | Objective | VLE activities |
|---|---|---|
| Science | Expand their knowledge in relation to plants, animals, and other natural elements<br>Describe and identify living beings, phenomena and elements observed in nature | Different objects are presented so that the child can identify and differentiate living beings or elements of nature<br>Coloring natural phenomena that are presented in different colors. In addition, living beings with certain characteristics (vertebrates, invertebrates, etc.) are shown |
| Technology | Use tools and develop fine and gross motor skills to help children develop hand-eye coordination<br>Identify age-appropriate technology resources that you can use | Putting together puzzles about technological devices<br>Coloring the outline of input and output devices<br>Assemble some technological devices, making them drag the elements that make them up |
| Engineering | Encourage brain development as children solve problems, using a variety of materials to build things<br>Strengthen their hand and finger muscles for handwriting, keyboarding, and drawing | They are asked to assemble some basic figures by color, shape, or number of pieces, etc. In addition, they are asked to assemble various elements of nature and that surround them at home and school<br>The child is also presented with actions related to the senses |
| Mathematics | Compare, match, and classify collections based on the number of items<br>Communicate orally and in writing the numbers in a variety of situations and in different ways, including conventional | Solve problems through counting and with actions on collections of items, associating objects with number<br>Relate the number of items in a collection to the written number sequence |

## 10.5 Conclusion-Discussion

The VLE's proposal coincides with what Noor (2021) pointed out about an early childhood education program based on five main areas of learning that develop: social, emotional, cognitive, language, and physical; NekuKids incorporates elements that contribute to the development of these aspects but focused on strengthening STEM. This was achieved through the participation of teachers in the selection of topics and the design of activities; their experience in the classroom, allowed them to define in greater detail those concepts or skills that should be emphasized to support children's learning.

NekuKids seeks to promote science in early childhood education in the same way as Ortiz and Cervantes (2015) to promote awareness of the role science plays in everyday life and interactions with the real world. This aspect was fulfilled with activities that the teacher can customize according to the context of his community.

When designing the learning environment, it was sought that it would not cause stress and anxiety of users due to unfamiliarity with the environment (Berg et al., 2021), this was achieved by using aspects known to the users (children, teachers, and tutors), such as the traditional layout of the interfaces, icons, buttons, etc. The use of the VLE was easy. And the VLE that it goes beyond children obtaining academic qualifications (UNICEF, 2019), but as can be seen in the pretest and posttest results, the children's knowledge of the topics covered in NekuKids improved.

Another aspect, which was incorporated into NekuKids activities, was noted by Chang et al. (2017), Vahlo and Karhulahti (2020), Erickson and Sammons-Lohse (2021), and Berg et al. (2021) on multitasking ability. It is associated with an executive function involving the performance of various cognitive processes, inhibition, working memory, and cognitive skills employed in everyday life, e.g., manipulating and recalling information to reinforce accuracy and motor, logical and mathematical challenges. In addition, it was considered that the instructions should be clear and easy to understand, and users should be able to track their progress.

An area of opportunity for the growth of NekuKids is the proposal of Noor (2021) to develop learning in preschool children because the teacher presents a problem, and the child looks for alternatives to solve it.

NekuKids is a virtual learning environment that is presented, together with other proposals mateMaroke (Nin et al., 2019), CHA (Vahlo & Karhulahti, 2020), eFun (Berg et al., 2021), and classDojo seek to contribute from their area of influence.

## References


Aranda, M. & Caldera, J. (2018). Gamifying the classroom as a strategy to foster social-emotional skills (Gamificar el aula como estrategia para fomentar habilidades socioemocionales). *Revista educarnos, 8*(31), 41–66. https://revistaeducarnos.com/wp-content/uploads/2018/11/educarnos31-1.pdf

Berg, V., McMahon, M., Rogers, S., Garrett, M., Manley, D. & Miller, G. (2021). A game-based online tool to measure cognitive functions in students. *International Journal of Serious Games, 8*(1), 71–87. https://doi.org/10.17083/ijsg.v8i1.410

Bertram, T. & Pascal, C. (2016). *Early childhood policies and systems in eight countries*. International Association for the Evaluation of Educational Achievement (IEA). https://link.springer.com/content/pdf/10.1007%2F978-3-319-39847-1.pdf

Chang, Y.-H., Liu, D.-C., Chen, Y.-Q., & Hsieh, S. (2017). The Relationship between online game experience and multitasking ability in a virtual environment. *Applied Cognitive Psychology, 31*(6), 653–661. https://doi.org/10.1002/acp.3368

Cheptoo, C., Violet, N., & Syomwene, A. (2018). Organization of learning environment in teaching language activities: a focus on ECD learners. *Journal Of Education And Practice*, *9*(15), 89–97. https://core.ac.uk/download/pdf/234641657.pdf

Cortés, A. & García, G. (2017). Teaching strategies to enhance learning in children from 0 to 6 years at Villavicencio Colombia (Estrategias pedagógicas que favorecen el aprendizaje de niñas y niños de 0 a 6 años de edad en Villavicencio Colombia). *Revista Interamericana de Investigación, Educación y Pedagogía, 10*(1), 125–143. https://doi.org/10.15332/s1657-107X.2017.0001.06

Dillon, M., Kannan, H., Dean, J., Spelke, E., & Duflo, E. (2017). Cognitive science in the field: A preschool intervention durably enhances intuitive but not formal mathematics. *Science, 357*(6346), 47–55. https://doi.org/10.1126/science.aal4724

Domingo J. (2019). *LMS: characteristics, usefulness, analysis (templates)* [LMS: características, utilidad, análisis (plantillas)]. juandon. Innovación y conocimiento. https://juandomingofarnos.wordpress.com/2019/09/07/lms-caracteristicas-utilidad-analisis-plantillas/

Driessen, G. (2018). Early childhood education intervention programs in the Netherlands: still searching for empirical evidence. *Education Sciences, 8*(1), 1-8.https://doi.org/10.3390/educsci8010003

Erickson, L., & Sammons-Lohse, D. (2021). Learning through video games: The impacts of competition and cooperation. *E-Learning and Digital Media, 18*(1), 1–17. https://doi.org/10.1177/2042753020949983

European Commission/EACEA/Eurydice. (2019). *Key data on early childhood education and care in Europe—2019 Edition.* Publications Office of the European Union. https://eacea.ec.europa.eu/national-policies/eurydice/sites/default/files/kdecec2019reporten.pdf

Fahad Al Saud, A. (2017). Educational video games enrich underprivileged children's social skills in Saudi Arabia. *European Journal of Educational Sciences*, *4*(2), 32–47. https://doi.org/10.19044/ejes.v4no2a3

Giménez, S., Hernández, A., Garrido, M. & Rabal, J. (2021). Gamification in the childhood education classroom. *South Florida Journal of Development, Miami, 2*(1), 623–632. https://doi.org/10.46932/sfjdv2n1-045

González, C. (2019). Gamification in the classroom: gamifying teaching-learning spaces and virtual spaces. (Gamificación en el aula: ludificando espacios de enseñanza- aprendizaje presenciales y espacios virtuales). https://doi.org/10.13140/RG.2.2.34658.07364

Guerrero, C. (2018). *I choose you!—Gaming as a digital learning ecosystem for Early Childhood Education* [Bachelor's Thesis]. Laurea University of Applied Sciences. https://www.theseus.fi/bitstream/handle/10024/156455/ichooseyoupdf.pdf?sequence=1&isAllowed=y

Heins, M. (2017). *Video games in education* [Master's Thesis]. University of New York. https://core.ac.uk/download/pdf/233574723.pdf

Idárraga, S., Álvarez, M. & Ríos, A. (2017). *Video games, a reality for the education of the children of C.ER. Buenos Aires, municipality of Santa Rosa de Osos, ANT.* (*Los videojuegos, una realidad para la educación de los niños del C.ER. Buenos Aires, municipio de Santa Rosa de Osos, ANT)* [Bachelor's Thesis]. Corporación Universitaria Minuto de Dios. https://repository.uniminuto.edu/jspui/bitstream/10656/6096/1/44-LOS%20VIDEOJUEGOS%2C%20UNA%20REALIDAD%20EN%20EL%20CER%20SANTA%20ROSA%20DE%20OSOS.pdf

Kokkalia, G., Drigas, A., Economou, A., Roussos, P. & Choli, S. (2017). The use of serious games in preschool education. *iJET, 12*(11), 15–27. https://online-journals.org/index.php/i-jet/article/view/6991

Mangieri, R. (2017). Kinesic and proxemic in urban environments: rhythms, entrainments, and synchronizations (Kinésica y proxémica en entornos urbanos: ritmos, entrainments y sincronizaciones). *Letra. Imagen. Sonido. Ciudad Mediatizada. 9*(17). 145–170. https://publicaciones.sociales.uba.ar/index.php/lis/article/view/3857

Marín-Navarrete, R. (2020, December 25). *Video Games: from Fun to Addiction* (Videojuegos: de la Diversión a la Adicción). Sanamente.mx. https://sanamente.mx/2020/12/25/videojuegos-de-la-diversion-a-la-adiccion/

Nin, V., Goldin, A., & Carbori, A. (2019). Mate Marote: Video games to stimulate the development of cognitive processes. *IEEE Revista Iberoamericana De Tecnologías Del Aprendizaje, 14*(1), 22–31. https://doi.org/10.1109/RITA.2019.2909958

Noor, S. (2021). The development of early childhood education in state of Kuwait using play as a medium of learning: A comparative study. *International Journal of Education and Research, 9*(1), 99–116. http://www.ijern.com/journal/2021/January-2021/09.pdf

OECD (2018). *Early Learning Matters.* OECD. https://www.oecd.org/education/school/Early-Learning-Matters-Project-Brochure.pdf

Ortiz, G. & Cervantes, M. (2015). Scientific training during elementary education. (La formación científica en los primeros años de escolaridad). *Panorama, 9*(17), 10–23. https://dialnet.unirioja.es/descarga/articulo/5585223.pdf

Papadakis, S. & Kalogiannakis, M. (2017). Mobile educational applications for children. What educators and parents need to know [Special Issue on Mobile Learning Applications and Strategies]. *International Journal of Mobile Learning and Organization, 11*(3), 256–277. https://doi.org/10.1504/IJMLO.2017.085338

Papadakis, S., Kalogiannakis, M. & Zaranis, N. (2018). The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece. *Education and Information Technologies, 23*(5), 1849–1871. https://doi.org/10.1007/s10639-018-9693-7

Petousi, V. & Sifaki, E. (2020). Contextualizing harm in the framework of research misconduct. Findings from a discourse analysis of scientific publications. *International Journal of Sustainable Development, 23*(3/4), 149–174https://doi.org/10.1504/IJSD.2020.10037655

Phillips, D., Lipsey, M., Dodge, K., Haskins, R., Bassok, D., Burchinal, M., Duncan, G., Dynarski, M., Magnuson, K. & Weiland, C. (2017). *The current state of scientific knowledge on pre-kindergarten effects*. Consensus Statement from the Pre-Kindergarten Task Force. https://www.brookings.edu/wp-content/uploads/2017/04/dukeprekstudyfinal4-4-17hires.pdf

Sampedro, B., Muñoz, J. & Vega, E. (2016). The digital video game as a mediator of learning in the Early Childhood Education stage. (El videojuego digital como mediador del aprendizaje en la etapa de Educación Infantil). *Educar, 53*(1), 89–107. https://ddd.uab.cat/pub/educar/educara2017v53n1/educara2017v53n1p89.pdf

Sebastian, T., Yammiyavar, P. & Jones, S. (2017). Product Design Strategies for Planned and Impulsive Buying: An Approach Based on FOGG's Model. Excellent Publishing House. In *Proceedings of International Conference on Research and Business Sustainability* (pp. 118–121). https://bit.ly/3jYS2ba

Shaari, M. F. & Ahmad, S. S. (2016). Physical learning environment: impact on children school readiness in Malaysian preschools. *Procedia - Social And Behavioral Sciences*, *222*, 9–18. https://doi.org/10.21834/ebpj.v5i15.2466

Soberanes-Martín, A., Olmos, S. & Martínez, M. (2020). Mobile Application to Exercise Oral Language from a Systems Approach. In S. Papadakis, & M. Kalogiannakis (Eds.), *Mobile Learning Applications in Early Childhood Education* (pp. 136–160). Hershey, PA: IGI Global. https://doi.org/10.4018/978-1-7998-1486-3.ch008

The Natural Learning Initiative. (2018). *Policy Brief: Achieving Quality in Outdoor Play & Learning Environments for Children Birth to Five.* The Natural Learning Initiative, NC State University. https://naturalstart.org/sites/default/files/staff/nli_policy_brief_2018.pdf

United Nations Children's Fund. (2019*). A world ready to learn: Prioritizing quality early childhood education.* United Nations Children's Fund (UNICEF). https://www.unicef.org/media/57926/file/A-world-ready-to-learn-advocacy-brief-2019.pdf

Vahlo, J., & Karhulahti, V.-M. (2020). Challenge types in gaming validation of video game challenge inventory (CHA). *International Journal of Human-Computer Studies, 143*, 1–13. https://doi.org/10.1016/j.ijhcs.2020.102473

Zirawaga, V., Olusanya, A. & Maduku, T. (2017). Gaming in education: Using games as a support tool to teach. *Journal of Education and Practice*, *8*(15), 55–64. https://files.eric.ed.gov/fulltext/EJ1143830.pdf

Zubairi, A. & Rose, P. (2017). *Bright and Early: How financing pre-primary education gives every child a fair start in life*. Real Centre, University of Cambridge. https://s3.amazonaws.com/theirworld-site-resources/Reports/Theirworld-Report-Bright-and-Early-June-2017.pdf

Zhai, X., Asmi, F., Yuan, J., Anwar, M., Siddiquei, N., Ahmad, I., & Zhou, R. (2021). The Role of motivation and desire in explaining students' VR games addiction: a cognitive-behavioral perspective. *Mathematical Problems in Engineering,* 1–10. https://doi.org/10.1155/2021/5526046

# Part III
# Educational Robotics

# Chapter 11
# From Construction Kits to Educational Robotics—Technology to Promote STEM Careers in Early Ages

**Martin Fislake**

**Abstract** Technical toys are among the early influences on the way young children behave, think and act. Their selection and the way they are used are significant from an educational point of view. Furthermore, studies show in particular repeatedly succeed in establishing an obvious connection between early play references and vocational and/or social orientation and STEM careers. At the same time, the range of toys on offer are reflecting the state of the art of the technological world while classically toys like construction kits are losing frequency of use and thus continuously changes the demand for fine motor and cognitive skills and other abilities from generation to generation. In response to this, various school and extracurricular activities are trying to implement the aforementioned research results in various STEM activities. In doing so, they want to contribute to improving basic technical education at an early age and use construction kits for this purpose that can seamlessly prepare the later use of educational robots. For the scope of this book this chapter gives an introduction into the history, the use and the characteristics of different construction kits, reports long term teaching experiences and the educational current use of it in selected learning scenarios.

**Keywords** Construction kits · STEM careers · Technology education · Robotics

## 11.1 Introduction

Regarding the history of construction kits, it turns out that they have always represented a mediator between playing and learning, whose development on the one hand depends on technical progress and its possibilities, but whose application and use are just as often closely linked to the educational intentions and pedagogical understanding of the respective epoch.

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In the context of their history, one of these intentions is associated with an integration into STEM career development applications at young age. But, given the time lag between intervention and impact career development is a lifelong process that needs research of life-span approaches as van Tuijl and van der Molen (2016) emphasizes.

Nevertheless, although applications and the evolution of construction kits is obvious and extensive documented from the early beginnings up to the 1990th there is a gap at the same time that roughly outlines their development and its background that followed since then and discusses the use and characteristics of current construction kits.

Therefore, a brief overview about related work with a focus on the history of construction kits related to education is given in this chapter sketching the development from early construction kits to current educational robotics. Also, an introduction into different perspectives and applications of construction kits is presented which is then connected to the use and specifications of modern educational robotic construction systems between toys and tools for STEM career development.

Thus, also refers to the assumption of Yagou (2020) "that despite the evident dissimilarities between construction sets and toy robots, there is a clear and strong conceptional thread that connects them."

It all may help to understand these systems as automated construction kits that follow the technical development as all former kits did before and to unfold its potentials to promote STEM careers in early ages.

### *11.1.1 Construction Kits*

The variety of construction kits nowadays ranges from simple (stackable) wooden building blocks, via plug-in (Fig. 11.1) and screw systems to electrified metal construction kits with lights, gears, actors, sensors and microcomputers. It indeed may often be their varying properties, such as how they fill space or how individual parts join together that suggest different approaches to construction.

With a broader focus they are well known as toys as well as building systems for teaching and learning purposes but also as systems to build mechanical applications like prototypes for research or machines. With regard to elementary schools and kindergartens, the industry-related applications are omitted, but nevertheless, with a few purely educational exceptions, they cannot completely hide their roots in most cases.

As an attempt to describe construction kits in general in more detail, Lingens (1999a) lists five criteria that he believes must be met. These are normalization, variability, reversibility, three-dimensionality, and constructive building. Parkinson (2007) takes this up later and describes construction kits therefore basically as sets of specialized, often precisely engineered, individual pieces that can reliably associate with each other in order to fill space. He still tries to distinguish between sets and kits, but avoids the term systems completely.

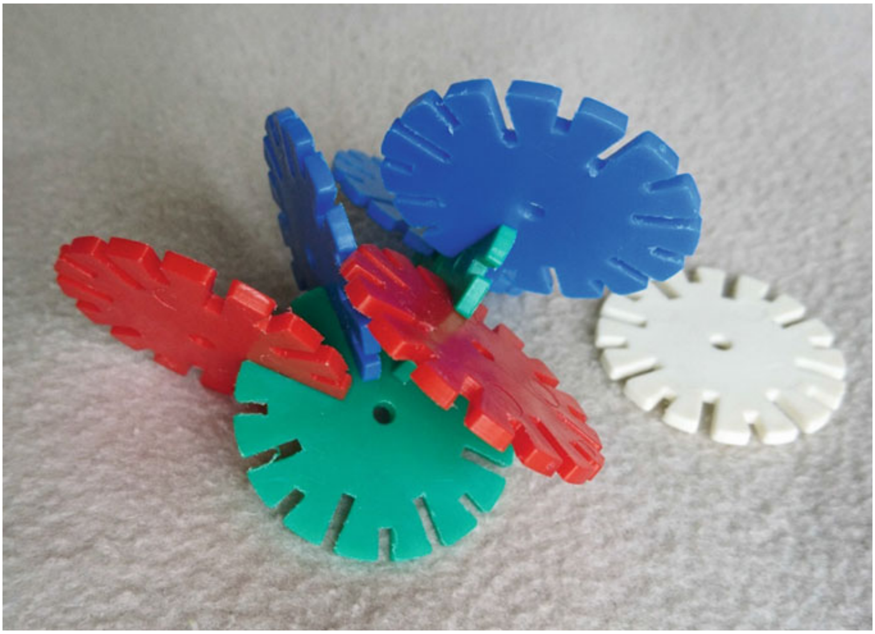

**Fig. 11.1** Example of a simple plug-in construction toy made of slotted plastic discs

Based on their particularly purposes another proposal is presented by Eisenberg et al. (2002). Their taxonomy of construction kits refers on three major dimensions of classification as there are: specificity of constructions, domain specificity and means of connection/construction materials. Moreover, they see still classifications: the intended audience and their specifics, the cost of materials, the kit's integration into learning scenarios and so forth.

From an early year's perspective, many kits have wheels, and some even offer early experiences with levers, cams and cranks as Parkinson (1999) stated. Some offer worksheets and building plans and some offer simple guide pictures. According to Fast (2006), they are used in schools to cope with predominantly constructive and constructive-functional problems in a model-like manner. From a classroom design perspective, construction kits can enable children to model design proposals before perhaps working in other materials.

In all cases, construction kits can be used to support work arising from a variety of contexts and, like permanent magnets in classroom science and other places, seem to be objects of interest and sources of motivation in their own right.

To close in the sense of Somyürek (2014) and Tzagkaraki et al. (2021) construction kits and robotic construction kits in particular offer opportunities to deepen the students' understanding of various concepts with hands-on exploration and design, resulting in fun and enjoyment. Children naturally wish to engage with them.

### 11.1.2 Construction Kits Between Toy and Tool

Construction kits, according to Almqvist (1994) and Parkinson (2004), have played a significant role in fostering the growth and development of children's (and adults') minds and manipulative-based skills in formal and non-formal educational settings.

Accordingly, the history of construction kits shows countless examples where, within the limits of technical possibilities, the development and assembly of a construction kit system was primarily prompted by pedagogical intentions. Here, the range of pedagogical understanding extends from the child's unintentional play to learning play to planned and structured learning scenarios to achieve a desired effect.

This is also how play entered the classroom in the nineteenth century, Jaffé (2006) describes, because in her view the goal was to make education more interesting.

This movement eventually gave rise to the terms "educational toy" and "learning through play", summarizes Jaffé (2006) and continues that today this part of toys is generally designed to stimulate learning and therefore, regarded for educational play, is sometimes also called instructive toys.

For Almqvist (1994), however, the term educational toy is much older than described by Jaffé (2006), since the purpose of toys has practically always been educational and describes how already in the late 1700s toy manufacturers advertised their educational toys and devices as improving toys.

According to Almqvist (1994), the Sputnik shock in the 1960s led to a decisive change in the attitude towards toys and finally to a separation between toys for learning and play purposes that cannot be justified any further and that additionally competes with the idea of creative toys.

Underpinned by target group and use-specific confections of the manufacturers of construction kits, this separation is still reflected today in the existence of nonrepresentational items as creative toys as well as in education and home versions of otherwise identical construction kit systems.

### 11.1.3 Construction Kits Between Invention and Business

Opposed to all educational intentions are the inventors and tinkerers, whose motivation is often rooted in the thing itself and who derive their satisfaction from technical success. While they often associate this success with the altruistic intention of having made a contribution to improving the world, this is contrasted by the primarily economic intentions of a third group.

Successful construction kits therefore always emerge in the context of a balance between inventiveness and technical progress, educational intentions and economic interests. However, this balance does not always succeed and history shows that only economically driven projects between these poles are able to survive comparatively unbalanced, while a subsequent balancing between the three poles can only be achieved in the long term and with great difficulty.

Regardless of this, most of the construction kits possess some characteristic features that reflect the respective Zeitgeist and technological change. Because, according to Yagou (2020) the creation of construction kits of the late nineteenth and early twentieth century were inspired by the architectural and technological environment while Parkinson (2004) argues these kits origins are rooted in the representation of the built world and now have a diversity of form and function, including technical versions with moving parts.

Therefore, the extension of construction kits to stone building kits, wooden, metal and plastic building kits by movable and moving parts is only logical and consequently to that. In the digitalized automation it only finds its current culmination and in educational robots a contemporary and expressive form.

### *11.1.4 Construction Kits and Life Course Research*

Much more complex than the multifaceted history of construction kits is the examination of the connections between intention, means, intervention and effect against a background of wanting to use construction kits as a pedagogical tool.

While in the past and today the causal relationships between effects of teaching scenarios seem to have been taken for granted on the basis of assumptions, experiences and plausibility, nowadays scientific evidence is sought on the basis of empirical data, whereby according to van Tuijl and van der Molen (2016) retrospective life course research once again plays a special role because of the time spans that have to be taken into account like Helwig (2003) did in his longitudinally study following children from age 7 to 17.

In concrete terms, this means that the short-term effects of interventions are much easier to prove by empirical methods than measuring long-term effects, whereas the probability of prediction decreases with increasing temporal distance between cause and effect.

This finally leads—theoretically-systematically seen—to the problem of the relationship between intention and effect in socialization, upbringing, education and teaching processes, as Herrmann (1987) states. At the same time, he expresses his principal skepticism about the prognostic value of theories that are based solely on educational-intentional actions.

With regard to construction kits, the uncertainty of the prognosis increases once again, because here, in addition to the fundamental problems of pedagogical predictions, the dynamic technical development and the resulting changes in the starting situations of the learners must also be taken into account. In the end, this means that children and young people who are involved in STEM do not automatically become engineers only because this has always been the case or was the case in the past.

### 11.1.5 Construction Kits and Technology Socialization

Pre-occupational socialization research, on the other hand, is much more targeted. It is process-oriented, less retrospective than life course research, and looks for the connections between socialization trajectories, habitus acquisition, and career entry into the labor market.

This kind of life-span approaches explain van Tuijl and van der Molen (2016) follow vocational psychology, emphasizes career development as a lifelong process and childhood as a formative period for it.

According to Krüger (1992), it asks about the socializing achievements of the institutionally multifaceted transition paths from school to work in a lengthening youth phase, while Ivemark and Ambrose (2021) depicts habitus acquisition as a product of socialization, which can be significantly shaped to a large extent in the family, but also by the immediate social environment, even at a young age.

Concentrating on an intended early orientation to technology-related topics and professions, technology socialization in particular plays an important role, as German Academy of Science and Engineering (acatech, 2009, 2011) points out.

More concrete Prenzel et al. (2009) emphasizes first of all, it is simply a matter of creating basic opportunities for experiences that are as comparable as possible for all children, especially those from educationally disadvantaged backgrounds.

Studies such as (acatech, 2009) show that early technical socialization is one of the decisive factors for a later orientation towards STEM professions. Positive key experiences made at home, in museums, on events (Fig. 11.2) or in schools influence the generation of interest towards technology and natural sciences was one of the findings from the study by acatech.

This refers to the science of familiarizing children and young people with technology at an early age in order to develop their interest and motivation to engage with technology. This process is scientifically called internalization and is initially triggered by parents, kindergarten and schools.

Papadakis et al. (2021) emphasize it and rate early childhood (from birth to age eight) as a crucial period for children's development. They see teaching STEM in childhood education settings as one of the most prevalent way to prepare students as future citizens in a society fundamentally based on technology.

However, successful technology socialization cannot be reduced to the promotion of interest in technology through key experiences, but also needs a continuous and sustainable technology education that includes a general maturity in technology and in dealing with new technologies.

Pfenning et al. (2002) and Ziefle et al. (2009) extend this approach and refer to studies from empirical social research, according to which successful engagement with scientific and technical topics requires a combination of interest, motivational dispositions and cognitive abilities. It is not enough that someone wants something, he must also be able to do it.

Consequently, Pfenning et al. (2002) extend this approach to technical education, as shown in (Fig. 11.3). It illustrates the relationships between the constructs of

Fig. 11.2 Large format wood and plastic construction system for very young children from MAXAMEC used in a STEM event

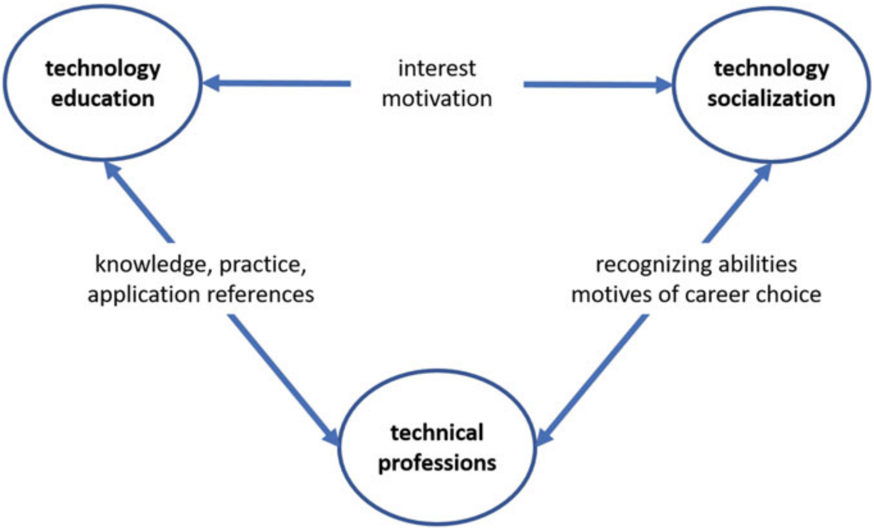


**Fig. 11.3** Interdependence of technical education, in accordance with Pfenning et al. (2002)

technical education, technical socialization, and technical professions as a social institution in which knowledge, application, and competence converge. The arrows indicate that this is a self-reinforcing process, i.e., outcomes of primary technology socialization can be reinforced by technology education or occupational experiences. It is therefore important that the various measures in the different areas of activity are coordinated with one another.

Nevertheless, technology socialization is considered as an important prerequisite for choosing a corresponding STEM occupation. On the one hand, it helps to identify individual abilities and skills in technology and the natural sciences; on the other hand, it contributes to social support for the corresponding career choice and to the positive perception of these professions (prestige).

Even if this imprinting does not guarantee a continuous interest in technology, acatech (2009) continues, it seems obvious that the area of early childhood education in the parental home, kindergarten, preschool and elementary school is becoming increasingly important for a successful technology socialization against this background.

For this very reason, acatach (2009) made a generative comparison between the promotion of older engineers and today's schoolchildren and came to the conclusion that traditional references to play are gradually being lost, that children today rarely deal with questions of how technology works, and that a change is taking place from the constructive to the consumptive or from the practical to the abstract (e.g., simulations).

At the same time, it is important to distinguish that they are not less technology-friendly than other generations as acatech (2009) emphasizes, but only that their way of looking at technology has changed. Put simply, individuals are changing from makers to predominantly unreflective users (acatech, 2009).

acatech (2009) goes on to say that technically gifted and interested children and young people need support despite many new support programs and projects. However, it is this technical socialization that is at the same time increasingly losing scope and diversity in the reality of our children's lives.

For it, it is precisely where young people's access to STEM is only made possible by the provision of suitable measures that the offers that enable them to participate in technology and the technical sciences as well as vocational orientation in the first place and help to recognize and promote talents play an important role.

## 11.2 Related Work

Relevant literature for a paper that seeks to connect and present the developmental history of construction kits with their use as a means of promoting computer sciences and STEM interests naturally draws from very different disciplines.

On the one hand, there are the more cultural-historical papers that focus predominantly on the development history of construction kits and their influencing factors and, on the other hand, the reports of efforts to promote technology education including STEM, computational thinking, and others from the educational perspective.

This is occasionally flanked by essays on the general history of toys like the one of Jaffé (2006), life stories of protagonists as Watson (2002) wrote one, and treatises by educational publishers, developers, and producers outlining their pedagogical considerations and intentions.

### 11.2.1 Related Work from the Classroom Perspective

With regard to the use of learning kits in the classroom, (Fast, 2006, 2008; Plickat, 2006; Sachs & Fies, 1977) have already elaborated the possibilities and limitations of their use against the background of curricula for teaching technology and the preceding explanations of the theoretical and didactic context of justification and assessment.

However, against the background of the educational reform of the sixties and seventies in Germany, Sachs and Fies (1977) focused predominantly on the school practice in technology teaching, while Fast (2006) also made a first approach to the characterization and classification of the different construction kit systems.

### 11.2.2 Related Work from the Historically Perspective

Leinweber (1999) and Noschka and Knerr (1986), on the other hand, focus more on the more historically accurate presentation of the history of the development of construction kits from their beginnings to modern times.

Except for a reference to LEGO Technic and the coming introduction of Cybermaster and Mindmaster (now known as Mindstorms, the author) in Leinweber (1999), both accounts avoid a discussion of the introduction of digital control elements. Thereby have Warnecke and Vettin (1979) described as early as 1979 how such control elements have been used for the simulation of complex manufacturing plants or have been already introduced in British schools with the BBC Buggy (Beesley, 1983; Bostock, 1983; Steeman, 1987). Both examples were based on mechanic elements of the fischertechnik construction kit which was invented by Artur Fischer in 1965.

The integration of motors, gears, and static, electromechanical, and electronic elements into the construction kits described is also only incidental in the cultural-historical view, while Tschorn (1979) already refers to the distinction made by the fischertechnik manufacturing company according to different user groups and thus immanently to digitization.

For in addition to a play program for children from the age of 6 years and a school program for all types of schools and school levels, fischertechnik also introduced a special industrial program for prototyping in development departments as well as for training and further education as early as the 1970s.

### *11.2.3 Related Work from the Pedagogical Perspective*

Parkinson, on the other hand, in his work from 1997 onwards, first traces the history of the transformation of construction kits since the end of the eighteenth century from a pedagogical perspective and connects them where possible with construction-based activities in schools (Parkinson, 1997; 1999).

Although he briefly mentions and evaluates the possibilities of 3-D simulation (Parkinson, 2004), the main focus of his work is to deal with practical, purely mechanical modeling tasks for children aged 3–11 years, following Fröbel's educational ideas, and to explore the relationships between designing and making concrete representations with a view to modeling (Parkinson, 2007).

Finally, he considers concrete modeling as an integral part of the overall design process, which, following Archer (1992) in addition to the help it contains for solving problems, also serves informational, experimental, evaluative, and communicative purposes.

Yagou (2020) in contrast discusses construction kits as objects created by adults for children. With a view on negative aspects like fear and frustration she also discusses their role in families in the second half of the nineteenth century between toys and tools and their use between education and entertainment.

## 11.3 Construction Kits as Educational Tools

Part of the history of construction kits is directly connected with the intention to use them as a means of education. A well-known and early example of this (from 1840) is Fröbel's Spielgaben, whose use in kindergartens was aimed in particular at comprehensive child development, while the development of metal construction sets at the latest also introduced the intention of vocational orientation, as Noschka and Knerr (1986) summarize in detail.

In their estimation, Hornby was convinced that users of his MECCANO kits (Fig. 11.4) would learn a number of other skills, attitudes and attitudes along the way, in addition to the essential principles of mechanics and manual dexterity, thus laying the foundation for a successful professional career.

Hornby was also convinced, according to Noschka and Knerr (1986), that every boy on earth has the talent to become a technician and that his metal building sets were particularly suitable for awakening this talent and teaching the basics of technical education. However, he presumably had the needs and interests of his sons in mind when he created the first construction kits around 1900 and only explicitly formulated


**Fig. 11.4** Parts of a MECCANO construction kit together with its motor, battery holder and cordless screwdriver from the 1990s

the career-oriented educational goals in the course of developing his construction kit system.

At about the same time, Korbuly invented the wooden MATADOR construction kit, which, in contrast to earlier, more static construction kits made of wood, enabled rotating movements with construction elements such as wheels, pulleys, gears and the like. In addition, according to Noschka and Knerr (1986), the manufacturing company of the MATADOR construction kits used an approval of their construction kits as teaching aids for schools for a larger turnover and in addition to research in developmental psychology, which was forced in the course of reform pedagogical innovation efforts of the 1920s.

It was believed that the MATADOR construction kits could be used to appropriately implement the new teaching principles owed to the school reform, such as independence and visualization. Despite the extensive program, however, one cannot speak of a systematic use in schools, according to Noschka and Knerr (1986). This only began after the educational reform in the 1970s, as will be described in the next section.

Another example can be carried out by the history of the Erector sets. This metal construction kit system was first envisioned 1911 in the US and originally patented by Alfred Carlton Gilbert. Gilbert was not the first adult to devote his life to toys, but he was the first to take toys and their influence seriously as Watson (2002) states. Gilbert called it engineering toys. He does not speak of education, but of toys for all kinds of scientific fun. He sincerely believed that children learn primarily by playing in the power of a toy and to open a mind makes a difference in the life of any child. To facilitate it he arranged an accompanying program including design contests, a magazine and an engineering level concept.

Against this background, Noschka and Knerr (1986) summarize the characteristic features of classic metal construction kits, which presumably still have their connotative effect today. From a retrospective perspective, they have the following common features:

Metal construction kits.

- were used to represent contemporary technology as models
- were intended to impart technical knowledge, skills and abilities as well as associated attitudes and behaviors
- were almost exclusively aimed at boys
- were adapted to political, social and economic trends

### *11.3.1 First Steps into Schools*

The use of construction kits as media for technical education became even more apparent as a result of the educational reform of the sixties and seventies in Germany. The consequences of the Sputnik shock in 1957 led to an appreciation of science and technology as educational content in schools, first in the United States and then in Europe. In addition, there were social developments that changed the view of toys as a learning tool altogether, according to Almqvist (1994).

From 1966 onwards, four congresses on craft education (Werkpädagogische Kongresse) in Germany argued about the introduction of basic technical education and restructured the established arts and craft lessons to a more technically oriented subject. The traditionally prevailing neo-humanistic educational content of art educational activity (Gaumer, 1979) was replaced by new subject didactics (Fast, 2008) and curricular syllabi for targeted technology teaching in primary and lower secondary education (Fast, 2008; Noschka & Knerr, 1986). Especially at the 2nd congress on craft education in 1968, the use of technical construction kits in schools was discussed in detail, according to Schaber (1977).

The development of appropriate methods and media, on the other hand, remained problematic for many years and was initially oriented to the experience of working with conventional free materials such as paper, cardboard, wood, metal, plastics, etc., as Fast (2008) reports.

According to his description, the central concern at that time to cope with mechanical engineering problems constructively and functionally ended in the disassembly and work analysis of moped or lawn mower engines or in the handicraft production of movement models made of wood, corrugated cardboard and other materials during the lessons.

Noschka and Knerr (1986) describe the models made in this way, including marble tracks made in group work, as very problematic and often non-functional and summarize that one of the main weaknesses of technical work with conventional material becomes clear above all in the blatant disproportion between work effort and pedagogical effect.

With the realization that the fulfillment of many of the learning objectives demanded in the curricula was impossible with conventional materials, a new sales market emerged for the fischertechnik construction kits.

According to Noschka and Knerr (1986), Artur Fischer was the only supplier in West Germany who responded immediately to the appeal of the work educators and showed willingness to adapt his construction kit system to the requirements of technology-oriented teaching in general education schools. In cooperation with the Technical Education Working Group at the Heidelberg University of Education, Fast (2008) added, he also developed extensive teaching materials, which he made available to all teachers free of charge. Over time, Fast (2008) continues, they evolved into more than a hidden curriculum, offering unsuspecting teachers' basic knowledge in a wide variety of areas. Schaber (1977) adds that fischertechnik offered the most help for teachers with its extensive range of manuals, brochures, and information pamphlets.

Especially for untrained teachers, the constant publication of new teaching examples was happily registered. Cooperation with textbook publishers such as Georg Westermann Verlag (Bickert et al., 1970) and teaching aid distributors such as Cornelsen Verlag further strengthened this effect. At that time, fischertechnik was unrivaled by other modular construction systems.

In East Germany, on the other hand, work with metal and plastic construction sets was introduced as compulsory for all general education schools as early as 1959, according to Schaber (1977). Thus, the metal construction kit "Construction CS1" from domestic production was firmly integrated into the curricula, Lingens (1999b) explains.

The kit was intended for technical handicraft lessons from the second and third grades onwards, which meant that the manufacturing company also benefited from cooperation with the schools. Other metal construction kits from the same manufacturer were used in schools and formed a concept-immanent bridge to vocational orientation within the framework of technical education in polytechnic classes.

While a phase of initial euphoria in the fischertechnik construction kit system was followed by a phase of stagnation in the school program towards the end of the 1970s for pedagogical, organizational and school policy reasons, the metal construction kits also disappeared widely from everyday school life.

Today, the manufacturer of the metal construction kit system construction again has a special school program in its assortment, which is enjoying a noticeable renaissance, especially among elementary schools, but has retained the old learning objectives. More about this in a later section.

### 11.3.2 Comeback Through Computing

Like the manufacturer of the metal construction sets, fischertechnik is also trying to build on earlier successes with its educational range. To this end, among other things, the system construction kits are continuously being supplemented with contemporary robotics applications, which are thus in direct competition with the robot construction kit systems from LEGO, VEX and others, which are established and widespread to varying degrees in different regions.

Renewed because the example of fischertechnik in particular shows that the system construction kit has always been able to adequately represent contemporary automation technology. However, after the school hype described above in connection with the emerging computers, an excursion into industrial simulation followed (Guertler, 1979; Warnecke & Vettin, 1979), for which with the help of special adapters, subsequently and in all consistency, the use of conventional industrial small controllers (PLC) was also made possible.

From 1984 onwards, fischertechnik itself launched so-called computing construction kits on the market, which could be connected via cables and suitable interfaces to the Commodore, IBM and other personal computers that were widespread at the time. A wired turtle was also available from 1987, while ECONOMATICS, as a result of the British Microelectronics Education Program (www.riscy.uk) in conjunction with the BBC program “Making the most of the Micro” (Bostock, 1983), already had an interface for the “BBC Buggy” on the market. The buggy was mechanically based on fischertechnik components, could be controlled via an Acorn home computer, and is said to have been widely used in English schools alone, with over 5000 units (www.riscy.uk). They were a consequence of the increasing spread and use of computers and the gradually growing pressure to teach information technology basics, programming, introduction to data processing and measurement and control in schools.

Even though the original computing construction kits from fischertechnik provided for the construction of various machines and robots, the originally used features as construction kits receded into the background. Instead, simulations and visualizations of disembodied data processing came to the fore.

Finally, in connection with the

- "Intelligent Interface” from fischertechnik (1997), with the
- "RCX” from LEGO (1998) and with the
- "VMC” from VEX-Robotics (1999),

the first controllers for mobile robot applications, which were suitable for schools and the masses and no longer depended on a cable connection, came onto the market at about the same time.

At the time, they were confronted with a situation characterized by the increasing spread of computers in general and the growing demand for computer literacy in schools. With large regional differences in distribution, established as well as new system construction kits now found new pedagogical fields of application in schools primarily as robot construction kits and less as modernized and automated construction kits.

In this sense Resnick and Silverman (2005) reflect their work on designing of a variety of new technologies for kids and conclude in respect to the ideas of Papert that most of their creations can be viewed as construction kits. This also applies if the system engages kids designing and creating things sometimes on the screen, sometimes in the physical world, sometimes both. They want do design construction kits to help kids explore and understand powerful ideas through providing opportunities for kids to encounter and use powerful ideas as a natural part of design experiences.

### *11.3.3 Basics Still Alive*

In comparison, the Spielgaben (toy gifts) developed by Fröbel are still popular in kindergartens in their basic shapes (sphere, cylinder, and cube), but also in many other variants, and are likewise available in the teaching materials trade.

They are flanked by wooden building blocks and construction kits, whose concepts are mainly based on the designs of Korbuly's MATADOR since 1901 and Wammetsberger's baufix since 1954, according to Noschka and Knerr (1986). Toy trains and marble tracks made of wood (Fig. 11.5) or plastic are also frequently available and expand the repertoire alongside various plug-in or clamping systems made of plastic.

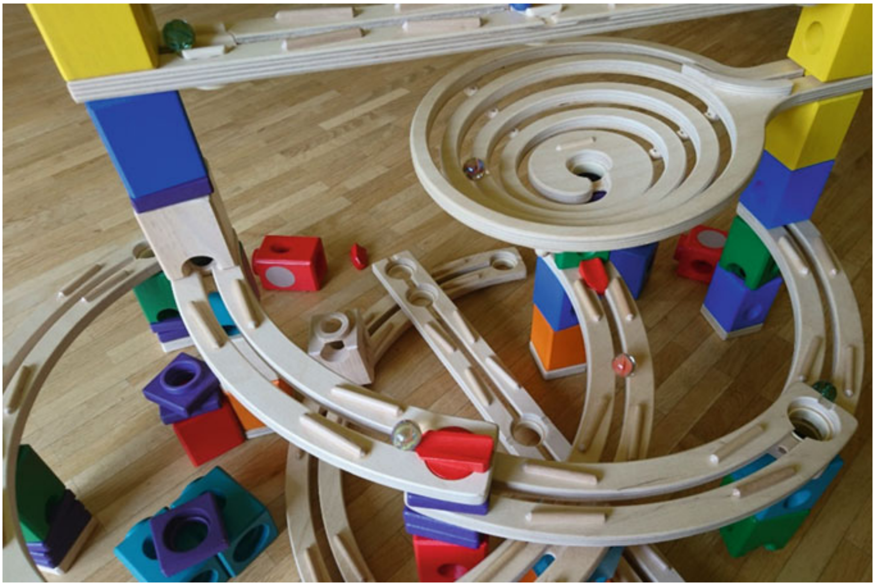

**Fig. 11.5** Comparatively elaborated wooden marble run for children 4 years and older

For Fröbel, the building sets he developed played a central role in the development of his system of play materials, in which material experiences are of fundamental importance for children and through which forms of life, cognition, and beauty can be conveyed (Noschka & Knerr, 1986).

As a means of representing other objects, the building sets according to Fröbel should form a system, which is used in analogy to today's developmental-psychological model conceptions and with further means of occupation such as laying boards, braiding materials, threads and chains, should correspond to the increasing abstraction ability and manual motor skills of the child.

In this respect, elementary building sets contain such nonrepresentational items as universally usable basic geometric shapes of colored or unpainted wooden building blocks. In contrast thematic building sets contain building blocks which, in a broader sense, reflect thematically oriented manifestations of building elements such as windows or doors or, in a narrower sense, are aimed at building a given model. When used correctly, they serve age-appropriate education and can therefore be categorized as educational toys, but do not really count as construction kits in the narrower sense.

Christie and Johnsen (1987) evaluate this early kind of play with nonrepresentational items restrictively as functional play, where the young child uses materials in simple, repetitive, and exploratory ways. Later play moves from functional play, to constructive play through adding a dramatic component with purposeful activities that result in creation, as Mogel (2008) states.

He explains, that the self-creation of a child's action replaces the mere joy of doing, as it was still typical for the simple functional plays. From his point of view the child is intrinsically motivated in construction play and wants to achieve a self-imposed goal with his play actions, while success or failure becomes the criterion for positive or negative emotions.

### *11.3.4 Keep on Rolling*

A special form of the construction kits are the marble tracks, which are based on the variety of materials used, but also on the range of content from art to science. Another special feature is the wide variety of forms they take, which are used institutionally in kindergartens as well as in elementary and lower secondary schools and thus represent a further link that goes much deeper into between play and scientific and technical experimentation.

The materials used range from all kinds of free materials, to plug-in systems made of wood (Fig. 11.5) or plastic (Fig. 11.6), to special forms of construction kits. Whereby the free materials are probably used more in connection with arts and craft and the system building elements more in connection with constructive activities from physics or technology education.

Common to all is the goal of keeping the sphere in motion as a dynamic element within the built construction, whereby ball tracks are all related to the ideas of

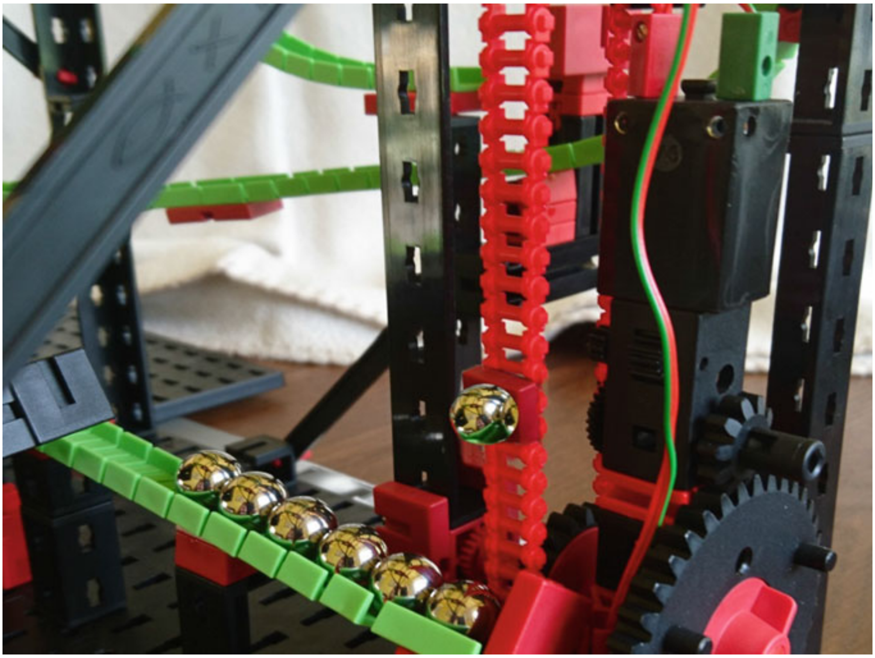

**Fig. 11.6** Ball track with electrically operated elevator from fischertechnik parts

Seymour Papert learning through design. Building itself thus represents a link between playing and learning, which is accompanied by three different forms of experimentation, which can be distinguished as follows, following Schmayl (1981):

**Playful experimentation**:

- Changes are perceived from the outside as "experimenting".
- The focus is on the joy of the unreflective observation of effects and of undirected action.
- Indirect learning that building is a lot of fun.

**Scientific experimentation**:

- Changes are intended to produce different effects based on altered conditions.
- They are causally oriented and are aimed at gaining knowledge.
- Direct learning to be able to understand the world by gaining knowledge.

**Technical experimentation**:

- Changes are intended to produce desired effects that are directed toward a specific purpose.
- They are final oriented and should fulfill a desired function.
- Direct learning to be able to shape the world according to one's ideas.

Against this background, it is not surprising that ball tracks based on construction kits, as shown in Fig. 11.6, are increasingly being equipped with building elements for automation, especially for older children, and are being promoted by the manufacturer as didactic experimental models for technical and scientific education.

## 11.4 Construction Kits to Promote STEM Careers

While it is not known whether the early protagonists of construction kits systematically evaluated their concepts, reports about their activities and resonances can at least be recognized as indications of an intended effect. Pfenning et al. (2002) even point out that the early playful references are congruent to an astonishing degree with the later profession as engineer or scientist. Nevertheless, due to the limitations discussed above, a long-term effect of technology education, socialization and habit acquisition on intended occupational socialization paths can only be assumed.

### *11.4.1 Applications Retrospective*

Noschka and Knerr (1986) illustratively support this assumption that technology education, socialization and habitus acquisition are related to intentional occupational socialization paths and quote, for example, a text from Pollock's Toy Museum (1984), according to which, following a conference in an institute for mechanical engineering about the lack of young engineers, the question was asked who had played with MECCANO in his youth. After everyone in the room had raised their hand, it was concluded that the early occupation with metal building sets could by all means have a corresponding effect.

The inventor of the computer, Konrad Zuse, also began his career with a metal construction set. As a teenager, he used the Stabil metal construction kit to build a model of a backhoe. After winning the design competition of the Walther manufacturing company with it in 1925, he used his experience of working with the construction system to build the first prototype of his computer.

Another example can be carried out by Gilbert with regard to his Erector sets. Having contact to his customers he reported on an ad for Erector sets about thousands young men who were "Gilbert's toy boys just a few years ago" are today making great strides in engineering.

Blyth (2012), on the other hand, examined whether the 1980s BBC Computer Literacy Project had a lasting impact on the culture of computing in the UK. At the time, the BBC started with a grand ambition to change the culture of computing in British homes and deployed the BBC Micro, accompanied in schools by the BBC Buggy, which was based on a structure made of the fischertechnik construction system. Their results after evaluating 292 questionnaires including detailed stories uncovered a significant and influential period of their lives that shaped the future careers of many people.

Less episodically, Oostermeijer et al. (2014) reported on their mediation analysis of 128 sixth graders in relation to constructive play, which generally involves the manipulation, construction, and movement of objects in space such as LEGOs, blocks, and puzzles. The goal was to examine the relationship between children's constructive play, spatial ability, and mathematical word-solving performance, as previously only an influence on spatial ability had been mapped in the literature.

Oostermeijer et al. (2014) conclude that spatial ability acted as a positive mediator in the relation between constructive play and children's mathematical word problem-solving performance. As a result, it is indicated that children who were frequently engaged in constructive play have better spatial skills and show a higher performance on mathematical word problems. Finally, with reference to acatech (2014), these two factors are among the pre-requisites for an early STEM orientation.

Quite differently focused Hudson et al. (2020) their research on the impact of an intervention based on a robotics-construction kit (LEGO WeDo) to interest in STEM subjects and careers. Thirty-seven elementary aged students participated in a sixteen-week long period two hours per week in building and coding sessions presenting their robots in a robotics showcase at the end.

They were accompanied by engaged and trained STEM-speaking adults, evidenced by acatech (2011) as another positive impact factor for STEM careers to children, who added information and ideas to student experience. Finally, their data indicates a positive impact on students' interest in STEM subjects and STEM jobs as a future career.

### *11.4.2 Current Applications*

Although there is no clear evidence of an intended impact relationship between engagement with STEM and an intended career choice (Ziefle et al., 2009), numerous formal and non-formal projects and programs are initiated around the world to do just that.

According to Ziefle et al. (2009), however, it is still unclear to what extent involvement with technical toys promotes sustainable structures of understanding and lasting interest in dealing with technical and scientific issues beyond a short-term interest in play. In particular, there is a lack of findings on the effectiveness of different types of technical toys and games for the development of a sustainable interest in technology.

Nevertheless, according to Ziefle et al. (2009), the initiators of STEM projects and programs see the use of technical games as an approach through which adolescents can experience the functioning and significance of technical phenomena and emphasize the importance of a combination of positively experienced playful interaction and one's own performance, evaluation and competition for their effectiveness.

acatech (2009) and Papadakis et al. (2021) go one step further and emphasizes the importance of appropriate framework conditions for successful technology education. Accordingly, schools need their own subject rooms, their own subject didactics, teachers well trained in technology education, and a differentiated range of courses to promote general interest in technology and to foster tech talents.

## 11.5 An Application in Formal Education

With the introduction of a metal construction system in so called technology-boxes in primary schools in Rhineland-Palatinate, the Ministry of Education is following up on recommendations from acatech (2009, 2011, 2014) and on those findings as discussed above from junior research on technology-related professions (Fislake et al., 2018).

With the decision for metal construction kits from eitech, the choice fell on a comparatively traditional technology toy that, like other construction kits, has proven its formative effect in earlier grades. It's a continuation of the "Construction" named metal construction kits mentioned above.

The potential of metal construction sets lies above all in the acquisition of positive key experiences, in the promotion of fine motor skills and spatial imagination. Even manipulative skills and hand/eye coordination which may be particularly important for girls as Williams and Jinks (1985) stated. Later, they also help to develop technology-specific ways of thinking and acting.

Thus, they serve to develop technical-constructive and technical-functional thinking as well as to develop the ability to imagine between symbolic representations like pictured in manuals (Fig. 11.7) and concrete models and, if possible, real objects, the originals. Williams and Jinks (1985) report their teaching experiences in primary schools where within the same class there may well be groups of children following the graphically building manuals but also a few who are able to handle exploded diagrams.

The introduction of the technology boxes in primary schools in Rhineland-Palatinate is not primarily about early vocational orientation, but about showing that technology didactic topics are part of a holistic general education. In this respect, they contribute to equal opportunities and offer individuals with an affinity for technology a talent-oriented and educationally appropriate option for action.

From a didactic point of view, metal construction kits belong to the group of construction kits, which by nature have a highly challenging character and a great capacity for self-instruction. Nevertheless, a short introduction to the handling of tools, components and fastening elements is recommended, especially for metal construction sets.

In this context, the classic three-step method: demonstrate—copy—do it yourself as shown in Fig. 11.8 has proven successful in order to be able to take along those who have less previous experience. After that, the motto can be: let them do, but don't leave them alone.

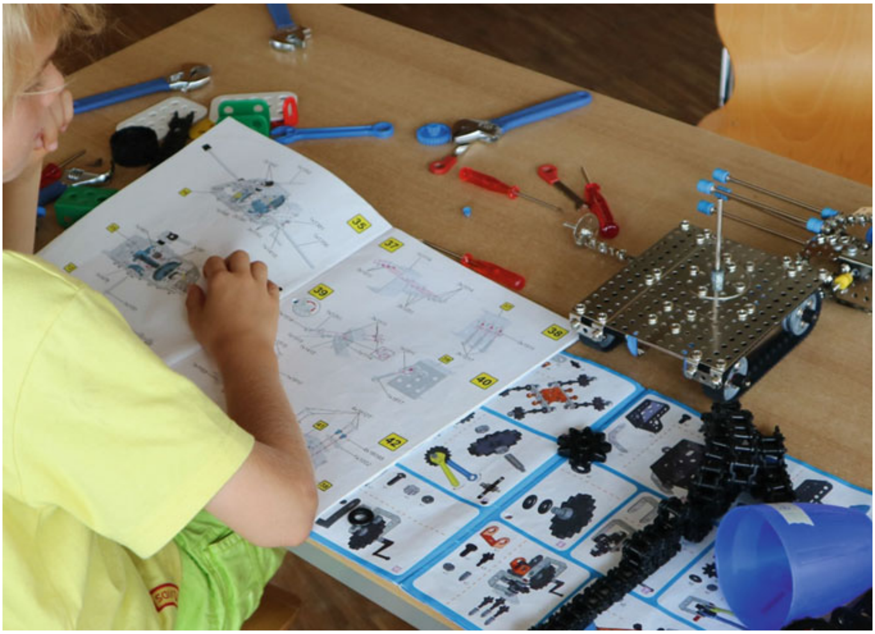

**Fig. 11.7** Manuals helping to understand and assemble complex constructions

The metal construction kits themselves have the advantages that they fall back on a tried and tested, classic and proven concept, are made of sustainable materials, use elements that are used in the same or similar way in industry and handicrafts, are comparatively stable and vandalism-proof, and have virtually no signs of wear and tear.

As a result, there is usually no need to buy additional consumables, but at the same time they leave open the option of supplementing the existing (basic) construction kits by purchasing (additional) kits or by using special extension kits to address specific topics. An example of this are the extension boxes for energy and solar technology including electric parts like motors, switches etc.

All in all, the metal construction system offers a variety of different uses in the school context. They range from use as free activity materials, to simple assembly tasks oriented to given building manuals plans, to construction tasks oriented to functional problems and combinations of it. The use in the context of reconstructions, i.e., the reconstruction of known constructions or for the construction of functional models for demonstration purposes, is also conceivable and feasible.

The metal construction kits can be used as free materials for occupation, in which, in analogy to other free materials, the design of the artefacts to be built can be completely free to the children. Perhaps the most important use of kits at the junior level will be to allow the child to model and to express ideas.

**Fig. 11.8** Showing how to handle the screwdriver the right way

A complementary decoration as can be seen in Fig. 11.9 offers in addition space for artistic creativity, enables a personal identification and will give the construction a personal note.

Compared to most other well-known and widely used free materials, metal building sets are today rather unknown by children and can lead to a certain polarization. This is where the classic technical construction kit meets the connotative legacy as boy's toys an aversion of contact with the material metal and curiosity about the design potential, i.e., what you can do with it.

The hint that one can't break anything and the encouragement to simply try things out help the fearful and the cautious to overcome their inhibitions and do the same as the curious. After a short time, imaginative meanings are assigned to the built artefacts, which then range from people and animals to vehicles, equipment and machines.

In contrast, the assembly tasks oriented to given construction plans represent the lowest level of challenge in the range of all structured possibilities for use. Of course, one can fall back on previous experience from free play, but from a didactic point of view, for the very first time it is recommended for most children, one must largely follow firmly planned processes and predetermined courses of action that have been fixed in the building instructions.

**Fig. 11.9** Giving the construction a personal note by decorating it

Williams and Jinks (1985) recommend also being clear about how materials can be used to extend, vary, and enhance learning opportunities. From their observations concepts children later derive from these materials are used to construct graphs, explain fractions, form quantities, and measure areas. They further recommend to consider whether it will be used by a group or individuals, for demonstration or explanation or as an aid to specific problem-solving situations.

While instructions limit the freedom of design, they also provide orientation and help the users to concentrate on the essentials or the next step. As the time of occupation becomes as reflective as possible and the level of difficulty increases, the ability to penetrate the constructs and anticipate the processes increases. Williams and Jinks (1985) supplement it as the child matures this appreciation of technology increases and he seeks to achieve greater reality in his models.

At the latest, the metal building sets are to be regarded as free construction materials that at the highest level of virtuosity opens new ways to creativity and in a certain way to innovation. The artefacts to be made by means of metal building sets can be combined with the task of mechanically rebuilding small constructions without instructions, such as a simple steering system or a ship's rudder, as well as with the task of reconstructing specific or arbitrary everyday objects.

Combined with the task of examining everyday objects in detail beforehand, seeing, observing and perceiving are also trained, while the concrete implementation follows on from the skills already developed to recognize and implement causal, constructive and procedural connections.

At the latest, special learning effects result from the use of professional terminology in connection with the proper handling of materials and tools at the workplace together with other children or adults. Because many of these kits are designed for group use (Fig. 11.10) as Williams and Jinks (1985) mention, there is therefore the further extension in a natural way group discussion context.

Consequently, the components of a model should be named, represented and assigned in a professional and appropriate (unambiguous) manner. This explicit wording and designations of components also facilitate communication when assembling, disassembling and, last but not least, when cleaning up.

However, component names can change as a result of a particular use. For example, a simple round bar can change its function to a torque-transmitting shaft or to a merely supporting axle.

Used in this way all construction kits are not presenting ready-made solutions but enabling the child to represent ideas to himself and to others and to see the results of action, the interrelationship of parts, through physical means.

The construction kits children work with must facilitate this and fortunately there is currently the good fortune of a wide selection of appropriate materials. Adding computational devices to make them tangible physical computing devices is only the next step.


**Fig. 11.10** Assembling a ferris wheel together in a group

## 11.6 Applications in Nonformal Education

Another place for the use of construction kits is the nonformal education section. As an example, selected courses of the so called technikcamps summer school project (www.technikcamps.de) at the University of Koblenz are outlined as follows.

Founded in 2003 as an out of school program from the age of 6 it is currently used to be a kind of a learning-teaching lab. Its program is seen as complimentary to established school subjects and offers a wide range of weekly courses on many different computer science and technology topics. In the courses themselves, the focus is on technology education and people design, build, screw, program, tinker and solder to their heart's content. Because construction kits are seen as valuable teaching tools and an integral part of STEM teaching in schools among them are some in which work is done with construction kits.

Mentoring is in most cases provided by students from the teaching degree programs with the subjects of technology education or computer science. To this end, the individual camps differ from one another in terms of concept and content in order to be able to meet the respective circumstances and the didactic demands as well as the training requirements of the students. Sometimes they are also used for research projects. Consequently, only a few of these courses build concretely on each other by means of different levels of difficulty, while others are used to evaluate new teaching approaches.

One of these courses for the 6–8-year old's offer the building of large fischertechnik models. In groups of 4 participants they can build, for example, excavators that are 1.40 cm long, 80 cm high and 50 cm wide, while learning about various drive, motor and transport techniques in a playful way. Because of their size, models like the one that can be seen in Fig. 11.11 have a particularly motivating effect on the participants and, once completed, encourage multi-faceted construction site play that reinforces the positive key experiences of successful construction.

As they grow up, they later design, build and program educational robots or a fully automated industrial simulation using the same building materials, but additionally with programmable microcontrollers appropriate for their age in each case.

Because the course offer is large and varied enough, the participants can also choose between the different systems of construction kits and follow their preferences. In conjunction with the concept of the teaching-learning lab technikcamps, they are thus introduced to innovative design scenarios that they might not come up with on their own and thus help to test the feasibility of a new teaching idea at the same time.

Thus, the well-known LEGO© construction system was upgraded with a CAD-software to a LEGO-CAD camp. The goal is to playfully retrace the practical path of the engineering design process from the idea to the functional model of an educational robot and to work one's way from computer simulations to a tryout of the prototype. For this purpose, programmable rovers are first designed on the screen with the age-appropriate LEGO-CAD (ML-CAD), then built and programmed from LEGO© building blocks and finally tested.

**Fig. 11.11** Electrified fischertechnik excavator, assembled and put into operation by a group of four 6–8-year-old children during a week-long summer camp workshop

It finally offers children and young people interested in a career in engineering opportunities to do what acatech (2014) says arouses their greatest enthusiasm: building and assembling things or to conclude in the sense of Resnick and Silverman (2005) to encounter and use powerful ideas. According, to various self-evaluations and feedback from parents (Kohlhage et al., 2016), everyone else takes away at least one positive key experience with them. In addition, the growing demand for such courses, the interest of parents in promoting their children's talents, and the high level of retention, with many of the participants coming back again and again, all speak for the success of the concepts and thus prove an already existing sustainable need for technology education.

## 11.7 Discussion and Implications

Even if one of the earlier roots of construction kits according to Noschka and Knerr (1986) lies in the playful inclination of children to recreate the world of large or nature with free materials, this finds its systematic continuation in the provision of prefabricated and standardized components. With the five typical characteristics according to Lingens (1999a): normalization, variability, reversibility, three-dimensionality and constructive building, they have always been considered a reflection of the times, which initially focused on the imitation of contemporary architecture with the offer of wooden and stone building sets.

In line with technological progress, new materials and construction kits gradually appeared, in which the components could be connected to each other in a fixed or movable manner. Well known milestones are the introduction of standardized distances and rotating axes, which found their logical and consistent continuation with the introduction of electrical, electronic and digital elements.

In this respect, current construction kits for building mobile robots only represent a continuation of this logic, which at the same time has a negative impact on the dissemination of other construction kit systems due to the lack of role models in everyday life.

Rather, they are "designing tools that allow children to add computation to traditional construction" as Martin et al. (2000) stated, because their components are not limited to the use as educational mobile robots or tangible physical computing devices, but can also be used for the reproduction of the most diverse manifestations of automated artifacts, i.e., precisely that traditional recreation of technological reality.

Moreover, playing and learning with construction kits is more than teaching engineering. According to Oostermeijer et al. (2014) they also have an importance of constructive play activities in childhood that are positively related to students' spatial skills, which, in turn, is positively related to their performance on mathematical word problems.

Knowing why to use construction kits and what to expect from them, teachers are in a position to support children in their play and discovery, to provide what direct instruction is necessary and to ensure that they have the skills and language necessary to let technology become understandable through experience.

As a result, it confirms what Papadakis et al. (2021) discussed. They argued the use of more educational-based educational tools seems to be one of the most prevalent ways to prepare students as future citizens in a technology driven society. It might yield the most significant benefits possible by helping children develop skills they will need. And at the same time, it may help to increase children's self-concept and interest in the field and provide information about relative career options (Papadakis et al., 2021).

Consequently, the use of educational robotics kits based on construction kits seems to be justified as a motivating, educating and perhaps a career-orienting element in general. Donohue (2020) in addition recommends to expand the view from a focus on preparation kids for a future STEM career. He believes that through authentic and engaging learning experiences children will be future ready when the time comes.

However, to limit robotic construction kits to the teaching of coding and computational thinking is a waste of their educational potential.

## 11.8 Future Research

As detailed as the explanations of construction kits given here may be, there are still gaps that could be filled. For example, it may be justified by the history and nature of the matter that it refers almost exclusively to the Western world. Nevertheless, it might be worthwhile to look at Asia, Africa and other regions to examine the history of construction kits and toys there and the use of construction kits related to constructive play and learning. Behind this, finally, lies the question of a transcultural universality of play and the meaning of toys in relation to different cultures.

At the same time, it is important to keep an eye on the effects of technical development on the forms of appearance of construction kits and their applications. For just as metal construction kits lost their appeal when the era of skeletal construction came to an end, simulations and additive manufacturing processes such as 3D printing are currently changing constructional paths. What happens to children when CAM and simulations are added to their constructive play while building an artefact in real and after.

## References

acatech—Deutsche Akademie der Technikwissenschaften. (2014). *MINT Nachwuchsbarometer*. Körber Stiftung.

acatech—German academy of science and engineering & VDI—The Association of German Engineers. (2009). Nachwuchsbarometer Technikwissenschaften. *Careers in Science and Engineering: Trends, Expectations and Attitudes of Young People*. Körber Stiftung.

acatech—German academy of science and engineering. (2011). *Monitoring von Motivationskonzepten für den Techniknachwuchs (MoMoTech)*. Springer.

Almqvist, B. (1994). Educational toys, creative toys. In J. Goldstein (Ed.), *Toys, Play, and Child Development* (pp. 46–66). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511527616.004

Archer, B. (1992). As complex as ABC. In P. Roberts, B. Archer, & K. Baynes (Eds.), *Design. Occasional Paper No. 1, Modelling: The language of designing* (pp. 7–11). Loughborough. Loughborough University of Technology.

Beesley, S. (1983). March of the Robots BBC Buggy. *Your Computer, 3*(4), 50–53.

Bickert, G., Meier, R., Radigk, W. & Wiederrecht, H. (1970). *Unterricht mit Lernbaukästen. Berichte—Erfahrungen—Vorschläge.* Braunschweig. Georg Westermann Verlag.

Blyth, T. (2012). *The legacy of BBC Micro. Effecting change in the UK'S cultures of computing*. 13.05.2021. https://www.nesta.org.uk/report/the-legacy-of-bbc-micro

Bostock, M. (1983). The BBC buggy. An adventure with technology. *Electronic systems News.*

Christie, J., & Johnsen, E. (1987). Reconceptualizing Constructive Play: A review of the empirical literature. *Merrill-Palmer Quarterly, 33*(4), 439–452. Retrieved June 5, 2021 from http://www.jstor.org/stable/23086403

Donohue, C. (2020). Foreword. In Waite-Stupiansky, S., & Cohen, L. E. (Eds.). *STEM in early childhood education: How science, technology, engineering, and mathematics strengthen learning.* Routledge.

Eisenberg, M., Eisenberg, A., Gross, M., Kaowthumrong, K., Lee, N., & Lovett, W. (2002). Computationally-Enhanced construction kits for children: prototype and principles. ICLS 2002. Proceeding.

Fast, L. (2006). Zur Genese von Baukästen im Technikunterricht. Von der Werkpädagogik zur Technischen Bildung. *Unterricht - Arbeit + Technik, 8*(29), 50–53.

Fast, L. (2008). Zur Genese von Baukästen im Technikunterricht. Neue Akzente für Technische Bildung. *Karlsruher Pädagogische Beiträge, 68*, 109–125.

Fislake, M., Orth, A., Birro, D., Gödickemeier, E., & Klag, T. (2018). *„Technikkiste"—ein Projekt zur Förderung des naturwissenschaftlich-technischen Lernens in der Primarstufe.* Pädagogisches Landesinstitut Rheinland-Pfalz.

Gaumer, W. (1979). Techniklehre und Studium. Reflexionen über ein Studienkonzept an der Universität Gießen. In G.P. Bunk, & R. Lassahn (Eds.), *Technik und Bildung* (pp. 94–115). Wiebelsheim: Quelle & Meyer.

Guertler, G. (1979). In Schachteln verpackte Weltraumtechnik. In G.P. Bunk, & R. Lassahn (Eds.), *Technik und Bildung* (pp. 202–207). Wiebelsheim: Quelle & Meyer.

Helwig, A. A. (2003). The measurement of Holland types in a 10-year longitudinal study of a sample of students. *Journal of Employment Counseling, 40*, 24–32.

Herrmann, U. (1987). Biographische Konstruktionen und das gelebte Leben Prolegomena zu einer Biographie- und Lebenslaufforschung in pädagogischer Absicht. *Zeitschrift Für Pädagogik, 33*(3), 303–323.

http://www.riscy.uk/beebcontrol/buggies/bbc_buggy/index.html

http://www.technikcamps.de

Hudson, M. A., Baek, Y., Ching, Yh., & Rice, K. (2020). Using a multifaceted robotics-based Intervention to Increase student interest in STEM subjects and careers. *Journal for STEM Education Research*, 3, 295-316https://doi.org/10.1007/s41979-020-00032-0

Ivemark, B., & Ambrose, A. (2021). Habitus adaptation and first-generation university students' adjustment to higher education: A life course perspective. *Sociology of Education.* https://doi.org/10.1177/00380407211017060

Jaffé, D. (2006). *The history of toys. From spinning tops to robots.* Stroud.

Kohlhage, S., Herrig, E. & Fislake, M. (2016). *Jahresbericht 2015.* http://www.technikcamps.de/medien/jahresberichte/2015

Krüger, H. (1992). Vorberufliche Sozialisation. *German Journal of Research in Human Resource Management,* 318–341.

Leinweber, U. (1999). *Schriften zur Volkskunde: Vol. 7. Baukästen: Technisches Spielzeug vom Biedermeier bis zur Jahrtausendwende.* Wiesbaden. Drei-Lilien-Edition.

Lingens, P. (1999a). Bausteine. Einleitende Betrachtung. In U. Leinweber (Ed.), *Schriften zur Volkskunde: Vol. 7. Baukästen: Technisches Spielzeug vom Biedermeier bis zur Jahrtausendwende* (pp. 12–33). Wiesbaden. Drei-Lilien-Edition.

Lingens, P. (1999b). Zwischen Rapp, VEB und eitech. In U. Leinweber (Ed.), *Schriften zur Volkskunde: Vol. 7. Baukästen: Technisches Spielzeug vom Biedermeier bis zur Jahrtausendwende* (pp. 140- 153). Wiesbaden. Drei-Lilien-Edition.

Martin, F., Mikhak, B., Resnick, M., Silverman, B., & Berg, R. (2000). To Mindstorms and Beyond: Evolution of a Construction Kit for Magical Machines. In A. Druin & J. Hendler (Eds.), *Robots for kids: Exploring new technologies for learning* (pp. 9–33). Morgan Kaufmann Publishers Inc.

Mogel, H. (2008). Das Kinderspiel: Motor der Persönlichkeitsentwicklung und Lebensbewältigung. In H. Mogel & K. Otto (Eds.), *Psychologie des Kinderspiels,* (pp. 153–211). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-540-46644-4_5

Noschka, A., & Knerr, G. (1986). *Baukloetze staunen: 200 Jahre Geschichte der Baukaesten.* Hirmer.

Oostermeijer, M., Boonen, A. J. H., & Jolles, J. (2014). The relation between children's constructive play activities, spatial ability, and mathematical word problem-solving performance: A mediation analysis in sixth-grade students. *Frontiers in Psychology, 5*, 782. https://doi.org/10.3389/fpsyg.2014.00782

Papadakis, S., Vaiopoulou, J., Sifaki, E., Kalogiannakis, M., & Stamovlasis, D. (2021). Attitudes towards the Use of Educational Robotics: Exploring Pre-Service and In-Service Early Childhood Teacher Profiles, *Educ. Sci.* 2021, 11(5), 204; https://doi.org/10.3390/educsci11050204

Parkinson, E. (1997). History and development of construction kits including a special study of Mobilo and Reo Click. *International Journal of Technology and Design Education, 2*, 32–37.

Parkinson, E. (1999). Re-constructing the construction kit—re-constructing childhood: A synthesis of the influences which have helped to give shape and form to kit-based construction activities in the primary school classroom. *International Journal of Technology and Design Education, 9*, 173–194.

Parkinson, E. (2004). An Examination of the interaction between modelling and its relationship with construction kits: Lessons from the past and for the future. *International Journal of Technology and Design Education, 14*, 219–243.

Parkinson, E. (2007). Practical modelling and hypothesis testing in primary design and technology education. *International Journal of Technology and Design Education, 17*, 233–251.

Pfenning, U., Renn, O., & Mack, U. (2002). *Zur Zukunft technischer und naturwissenschaftlicher Berufe*. Universität Stuttgart/Akademie für Technikfolgenabschätzung in Baden-Württemberg.

Plickat, D. (2006). Baukästen in der Grundschule. Attraktiv—anschlussfähig—alltagstauglich. *Unterricht - Arbeit + Technik*, 8(29), 46–49.

Pollock's toy museum (1984). *Meccano Ltd. -Short history from Pollock files*. London.

Prenzel, M., Reiss, K. & Hasselhorn, M. (2009). Förderung der Kompetenzen von Kindern und Jugendlichen. In J. Milberg (Ed.), *Förderung des Nachwuchses In Technik und Naturwissenschaft,* (pp. 15–60). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-01123-8_1

Resnick, M. & Silverman, B. (2005). Some reflections on designing construction kits for kids. In M. Eisenberg, A. Eisenberg & M. Eisenberg (Eds.), *Proceedings of the Interaction Design and Children 2005*, Boulder, Colorado: ACM, (pp. 117–122). https://doi.org/10.1145/1109540.1109556

Sachs, B., & Fies, H. (1977). *Baukästen im Technikunterricht.: Grundlagen und Beispiele.* Ravensburg: Otto Maier Verlag.

Schaber, J. (1977). *Technische Baukästen in der Schule—ein Beitrag zur Didaktik des Technikunterrichts in Grund- und Hauptschulen*, Dissertation. Aachen: Pädagogische Hochschule Rheinland, Abteilung Aachen.

Schmayl, W. (1981). *Das Experiment im Technikunterricht - methodologische und didaktische Studien zur Grundlegung einer Unterrichtsmethode.* Franzbecker Verlag.

Somyürek, S. (2014). An effective educational tool: Construction kits for fun and meaningful learning. *International Journal of Technology and Design Education, 25*(1), 25–41. https://doi.org/10.1007/s10798-014-9272-1

Steeman, J.P.M. (1987). *Robotik mit dem Heimcomputer. Der Einstieg in die faszinierende Welt der Robotertechnik*. Aachen: Elektor.

Tschorn, D. (1979). Geschichte der Baukästen. In G. P. Bunk, & R. Lassahn (Eds.), *Technik und Bildung.* Wiebelsheim: Quelle & Meyer.

Tzagkaraki, E., Papadakis, St., & Kalogiannakis, M. (2021). Exploring the Use of Educational Robotics in primary school and its possible place in the curricula. In M. Malvezzi, D. Alimisis, & M. Moro (Eds). *Education in & with Robotics to Foster 21st Century Skills. Proceedings of EDUROBOTICS 2020*, Online Conference February 25–26, 2021, (pp. 216–229), Switzerland, Cham: Springer, https://doi.org/10.1007/978-3-030-77022-8_19

van Tuijl, C., & van der Molen, J. H. W. (2016). Study choice and career development in STEM fields: An overview and integration of the research. *International Journal of Technology and Design Education, 26*(2), 159–183. https://doi.org/10.1007/s10798-015-9308-1

Warnecke, H. J., & Vettin, G. (1979). Funktionsmodelle komplexer Fertigungsanlagen aus Bausteinen der ‚fischertechnik'. In G.P. Bunk, & R. Lassahn (Eds.), *Technik und Bildung* (pp. 161–179). Wiebelsheim: Quelle & Meyer.

Watson, B. (2002). *The man who changed how boys and toys were made.* New York, NY: Viking.

Williams, P., & Jinks, D. (1985). *Design And Technology 5–12* (1st ed.). Routledge. https://doi.org/10.4324/9780203985908

Yagou, A. (2020). The other side of play: Fear and frustration in the design, consumption and use of construction sets. *Journal of Design History, 33*(3), 193–208. https://doi.org/10.1093/jdh/epaa029

Ziefle, M., Jakobs, E.-M. & Arning, K. (2009). *Wege Zur Technikfaszination. Sozialisationsverläufe und Interventionszeitpunkte* (Acatech DISKUTIERT). Berlin: Springer. https://doi.org/10.1007/978-3-642-04983-5

# Chapter 12
# Taxonomy of Floor Robots for Working on Educational Robotics and Computational Thinking in Early Childhood Education from a STEM Perspective

**Juan-Francisco Álvarez-Herrero, Rosabel Martinez-Roig, and Mayra Urrea-Solano**

**Abstract** Educational robotics and computational thinking are increasingly present in the Early Childhood Education classroom. In many educational centers and plenty of Early Childhood Education classrooms, floor robots are beginning to be used as resources that promote the development amongst students of a variety of competences that go beyond computational thinking. Nevertheless, that implementation of robots inside the classroom is very often being performed without any planning, lacking in methodology and seeking no specific goal. An urgent need exists to establish some criteria or premises that can orient teachers in a first choice of the floor robots best suited to their students' needs. This chapter undertakes the analysis of eight common floor robot models in the hope that it will allow us to establish a set of basic principles which can provide Early Childhood Education teachers with guidance for their choice and in turn serve as approaches worth considering in any intervention aimed at implementing educational robotics and computational thinking during this educational stage.

**Keywords** Educational robotics · Taxonomy · Floor robots · Early childhood education

## 12.1 Introduction

The development of the various STEM disciplines becomes essential in technologically advanced societies. Hence their growing presence in educational systems around the world. Working under a STEM approach has become a true challenge for current teachers, and they are starting to be introduced in numerous university

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institutions, not only in those education degrees meant to train future teachers but also in other types of university degrees, even if they are completely unrelated to education.

Thus, a STEM approach to society as a whole is favoring a greater presence of such disciplines in every field, and accordingly boosting a more in-depth development of human knowledge (in all its disciplines), as well as people's ability to learn.

When it comes to the educational world, the introduction and relevance of STEM disciplines across the different educational stages and centers remain largely uneven. Many countries still attest the non-existence of an action plan as well as the lack of a clear, committed inclusion of these disciplines. All the same, their implementation in classrooms is becoming more and more widespread. Therefore, by way of example, the utilization of robotics and computational thinking as an educational resource from a STEM perspective is increasingly frequent (Casey et al., 2018; Fislake, 2018, 2022; Friedberg & Redfors, 2021). This use makes it possible both to break barriers and minimize the gender gap (Reinking & Martin, 2018; Çetin & Demircan, 2020; Greca et al., 2020) and also to improve students' learning (García-Valcárcel & Caballero-González, 2019; Olabe et al., 2014).

This chapter precisely has as its aim to address the presence of robotics and computational thinking in the Early Childhood Education stage. More specifically, attention will be paid to how floor robotics is used during this educational stage. We will likewise see and analyze eight floor robot models, with their characteristics, advantages and drawbacks, thus seeking to establish a first approach to these robots which can orient and guide all those educational centers and professionals of this field that want to introduce educational robotics and computational thinking in Early Childhood Education.

Other studies carried out have highlighted the need to classify and organize educational robots (Catlin et al., 2018, 2019; Papadakis, 2020; Patiño-Escarcina et al., 2021), and in our case, we wanted to go further, and in addition to establishing this classification, we have delved into the criteria that a floor robot should have in order to allow the development of computational thinking among Early Childhood Education students. We also show a comparative analysis of eight models, chosen at random, of floor robots, with the idea of helping teachers to see how they can carry out a similar analysis and with it, help them decide which robot to choose.

If we want to incorporate educational robotics and programming for the development of computational thinking among Early Childhood students, we must make sure that the teachers who are going to do it are well trained and that when choosing which devices, they want to do it with, the teachers attend to quality and suitability criteria (Camilleri, 2017; Casey et al., 2021; Castro et al., 2018). This chapter adds as a novelty an analysis of these criteria, as well as an example of the analysis of eight models of floor robots, chosen at random, so that it can be of help to teachers.

## 12.2 Educational Robotics and Computational Thinking in Early Childhood Education

It is widely proven that educational robotics, together with computational thinking and programming, favor the development of various skills and competences, amongst which stand out: analysis, initiative, problem solving, creativity, cooperative work and learning to learn (Di Lieto et al., 2017; Ioannou & Makridou, 2018). However, it all has to face numerous problems and inconveniences, both of an intrinsic and an extrinsic nature, as well as criticism from several groups:

- the high cost of these devices;
- their difficulty of use both for such young students and for teachers;
- the low extent to which teachers perceive these practices as being useful;
- a wrong use of these resources which can result in it becoming a merely playful practice from which no learning derives;
- the implementation of robotics in this stage is not described in the curriculum;
- the absence of support by the center's management team;
- the lack of funding;
- an isolated, decontextualized use; and
- the excessively early introduction of robotics in Early Childhood Education.

This leads to an uneven presence of robotics in Early Childhood Education classrooms. While used constantly and purposefully in some classrooms, it only appears sporadically and on an occasional basis in others. And classrooms also exist in which neither the application of robotics nor its use are considered.

This uneven implementation reflects another aggravating factor, i.e. whether teachers are sufficiently trained and qualified to bring robotics into classrooms. Although floor robotics does not require a highly qualified training for such devices to be used, their pedagogical utilization does raise the need for specific training, alongside planning and a methodology through which these practices can be more than a simple game (Kalogiannidou et al., 2021). Practicing teachers have been provided with a growing volume of training in robotics from educational administrations and teachers' centers during the last few years. The training offered is in great demand and widely welcomed by teachers. Similarly, universities are starting to include these issues associated with robotics and computational thinking in the initial training of future teachers, arousing a great deal of interest amongst students too (Álvarez-Herrero, 2019; Casey et al., 2020; Papadakis et al., 2021). Nonetheless, the training of current and future teachers in educational robotics as well as its didactic implementation in the classroom remains insufficient, and neither it reaches all teachers nor every teacher is willing to implement it.

On another note, it is worth highlighting families—an active part of the educational community. Their decision when choosing one educational center or another for their children often relies on whether or not such centers use certain methodologies and innovative resources. Educational robotics plays a key role in this regard since it acts as an incentive. An example thereof is the case in which Early Childhood Education students utilize robots that recognize their face and record videos which are sent to parents, who can see in real time how their children interact and learn in the educational center (Dongming et al., 2020).

It also becomes necessary to consider the perceptions that current and future Early Childhood Education teachers have about robotics and computational thinking (Papadakis & Kalogiannakis, 2020; Papadakis et al., 2021; Román-Graván et al., 2020), as well as the uses and functions given to them by those who apply these resources in their classrooms. Thus, teachers' perceptions about their utilization are positive (Álvarez-Herrero, 2020) but it would be highly advisable to check that, for example, those teachers understand and can clearly distinguish between robotics, computational thinking and programming. Concerning their possible utilization, floor robots are most frequently used to foster the development of competences and skills amongst students (Zviel-Girshin et al., 2020), even though this feature, due to the lack of training and/or planning, runs the risk of exploiting only the fun component of these devices, thus exclusively succeeding in motivating and attracting students. A completely different matter is whether we manage to integrate playing and robotics (Meadows & Rodney, 2021), in which case greater benefits are achieved.

Hamilton et al. (2020) tried to shed light on the utilization of computational games and the different tools available to learn and develop computational thinking amongst Early Childhood Education students. They not only categorize computational games but also dare to assess the effectiveness of such devices when it comes to teaching and developing learners' computational thinking. A total of six categories were established by these authors: (1) Board games and books; (2) Non-robotic electronics; (3) Screen-based robots; (4) Button-operated robots; (5) Robots with a tangible interface; and (6) Blended (which may mix two or three of the previous options).

## 12.3 Floor Robots in the Context of Early Childhood Education

At this point, the need arises to devise an action plan or learning plan. The latter must have clear objectives and foresee carefully-thought and well-grounded actions related to whatever we want students to learn. It is additionally necessary to reflect on the convenience of choosing some devices or others when carrying out that implementation. Concerning this, numerous voices speak about a greater suitability of floor robots in this educational stage for the familiarization with educational robotics and computational thinking.

Albeit still incipient, studies on best practices in educational robotics and computational thinking development performed with floor robots amongst Early Childhood Education students are beginning to surface. By way of example, some deal with the improvement of computational thinking as well as other competences and skills of learners (Angeli, 2021; Caballero & García-Valcárcel, 2018; Di Lieto et al., 2019; Glezou, 2020; Roussou & Rangoussi, 2020; Vizner, 2017), whereas others refer to fun-oriented experiences that seek to combine the digital and the analogical (Arnott et al., 2019), the latter remaining an essential aspect which must be present in this educational stage.

Therefore, although experiences exist which refer to their use, very few research works have carried out a comparative analysis in search of the best floor robot model for the purpose of configuring that model, or of informing decision-making processes about their inclusion in the classroom (Papadakis, 2020). Hence the need to assess the different floor robots available in the market according to quality criteria, which will make it possible to identify the robot or robots which constitute the best possible choice.

It is also very important that, in order to make a correct choice of floor robots that can be used in the early childhood classroom, in addition to considering a series of quality and suitability criteria, the teachers who are going to make said choice, they should have received training in robotics and programming (Bers et al., 2013). If the teachers have knowledge of robotics and programming, they will be better able to know which robot will best suit the learning objectives that they intend to achieve with their students (Elkin et al., 2014). In this way, teachers become designers of learning, use concrete objects so that their students are able to build and explore the world, and also self-reflect on the learning process (Bers et al., 2002).

As we have just seen, making a good choice of floor robots to be used in Early Childhood Education is a problem that has previously concerned by other authors (Bers, 2008; Bers et al., 2014; Kazakoff et al., 2013) and also recently (Kalogiannakis et al., 2021; Tzagkaraki et al., 2021).

In the course of a previous study, we built an instrument for this analysis, the so-called "FAREI card" (Álvarez-Herrero, 2021) (Fig. 12.1) which takes into account all the technical, descriptive and pedagogical aspects related to these devices. This card can be utilized both by teachers on an individual basis and by educational teams for their classrooms and centers. When filling it out, they will have to consider the most immediate context or environment of their classrooms and students, with their particularities and idiosyncrasy. It was built and validated from the validation work carried out by 50 experts in the use of educational robotics in Early Childhood Education from various fields: Early Childhood Education teachers; educational-commercial technicians in educational robotics; and university lecturers with a broad experience over years of educational robotics teaching in the training of future Early Childhood Education teachers. The card includes instructions so that users can correctly complete all the fields appearing therein (Figs. 12.2 and 12.3).

## 12.4 Floor Robot Taxonomy. The FAREI Card

We deemed it appropriate to undertake a descriptive, detailed analysis about some of the floor robots available in the market for the Early Childhood Education stage. The aim sought thereby is to favor an initial approach to these devices, highlighting their strengths and weaknesses. Although some analyses exist which pursue the same

| | | |
|---|---|---|
| Name/Model: | | |
| Brand/Publisher: | Price: | |
| Purpose: | | |
| Description: | Image: | |
| Recommended age: | | |
| Instructions for use: | Instructions' language(s): | |
| Resources available: | Accessories available: | Customer service: |
| Movement: | Optical signals: | Audio: |
| Aesthetics: | Robustness: | |
| Batteries/Battery/Recharge: | Autonomy: h. | |
| Manufacturing material: | Does it have small parts?: | |
| Programming type: | Maximum number of orders: | Where is it programmed from? |
| Difficulty to assemble by students: 0-1-2-3-4-5 | | |
| Difficulty to handle by students: 0-1-2-3-4-5 | | |
| Skills and competences which it develops: | | |
| Main advantages: | | |
| Main disadvantages: | | |
| Final assessment: 0-1-2-3-4-5 | Quality/price ratio: low / medium / high | |
| Analysis made by: | Date: | |
| Remarks: | | |

**Fig. 12.1** FAREI card for the taxonomy and classification of floor robots. *Source* extracted from Álvarez-Herrero, 2021

| |
|---|
| **Name/Model:** Include the robot's name and model |
| **Brand/Publisher:** Brand, company or publisher which sells the robot |
| **Price:** Include the approximate price, if possible, also the shop, company or url |
| **Purpose:** In the teacher's words, which is the robot's use or purpose |
| **Description:** In the teacher's words, describe the robot |
| **Image:** Include one or several images of the robot, together with its components |
| **Recommended age:** Establish an approximate age range for its use |
| **Instructions for use:** In the teacher's words, how the robot is handled/used |
| **Instructions' language(s):** In which language(s) the manufacturer's instructions are |
| **Resources available:** Is it accompanied by a facilitator's guide with educational possibilities?<br>Is there a community on the Internet which shares activities, experiences, and so on?<br>Can resources be created for its use? |
| **Accessories available:** What accessories does it have or can be bought which are compatible with the robot? Is it possible to extend them in order to use it at a higher age range? |
| **Customer service:** If there is customer service, include the contact telephone number, email or address. Do they only help with technical problems or also with pedagogic ones? Does the robot have spare parts? Does the robot have a warranty? |
| **Movement:** Is it through panels? If it is, what are the panels' measurements? 15x15? 20x20? Are the movements precise of does it have errors which need to be constantly corrected? |
| **Optical signals:** Lights, text display, graphic display? |
| **Audio:** Sounds, music, repeated sound, etc? Can they be switched off? |
| **Aesthetics:** Is it adjusted to the recommended age? Does the robot's aesthetic create emotiveness? |
| **Robustness:** Does it stand falls, involuntary blows, etc? What average shelf-life does it have? |
| **Batteries/Battery/Recharge:** What type of batteries does it have? Are they easily changed/recharged? |
| **Autonomy:** **h.** With new or recently charged batteries, how much runtime is it guaranteed? |
| **Manufacturing material:** What materials have been used to make the robot? Is there any warning related to possible allergies? |
| **Does it have any small parts?:** Does it have any small parts which make it inappropriate for that age? |
| **Type of programming:** Through codes, blocks or panels, scratch or other? Is it simple or not? |
| **Maximum number of orders:** if it is specified or if it has been studied, what maximum number of orders does it accept? |
| **Where is it programmed from?:** from a control or panel, from a tablet, a mobile phone, a computer, etc?, and how is that device connected to the robot: via Wi-Fi, Bluetooth, USB cable, etc? |
| **Difficulty to assemble by students: 0-1-2-3-4-5** If it does not need to be assembled, it is 0. If it is complicated to assemble, it is 5. |
| **Difficulty to handle by students: 0-1-2-3-4-5** If it is very easy or very predictable to handle, or there is no need to handle it at all, it is 0. If it is very complicated to handle or no intuitive at all and requires the teacher's involvement, it is 5. |

**Fig. 12.2** Explanation of the FAREI card for the taxonomy and classification of floor robots, 1 of 2. *Source* extracted from Álvarez-Herrero, 2021

| |
|---|
| **Skills and competences which it develops:** what competences does it develop? Programming, spatial orientation, computational thinking, movement sequence, collaborative work, problem solving, creativity, socialisation, etc. |
| **Main advantages:** the robot's strengths |
| **Main disadvantages:** the robot's weaknesses |
| **Final assessment: 0-1-2-3-4-5** The total score I would give the robot |
| **Quality/Price ratio: low / medium / high** Regarding the relation between its performance and its price, which is the ratio, being high the best one. |
| **Analysis made by:** Name of the teacher who is making the analysis |
| **Date:** Date on which the analysis has been made |
| **Remarks:** Other aspects which have not been considered in the previous items, such as:<br>Can it be connected via Wi-Fi or Bluetooth?<br>Is it apt for students with any type of disability or learning difficulties?<br>Is it possible to adapt the robot to different age ranges?<br>Are there any needs regarding space and organisation/interaction to work with the robot: panels, floors, boards or table covers; and is it for individual, pairs, small groups, large groups, etc.<br>Type of activities which can be created with the robot, their duration, etc.<br>The robot's transport and storage<br>Etc. |

**Fig. 12.3** Explanation of the FAREI card for the taxonomy and classification of floor robots, 2 of 2. *Source* extracted from Álvarez-Herrero, 2021

aim (Catlin et al., 2018, 2019; Papadakis, 2020), unlike those, our examination of floor robots for Early Childhood Education will be based on using the FAREI card, which permits to ascertain the drawbacks, problems and criticism that are attributed to these practices. This card refers to a global set of all fields, grouped into six blocks (description; technology; pedagogical component: skills and competences (which) it develops; advantages and drawbacks (which) it brings; assessment and value for money; and remarks), which allowed us to carry out a thorough comparative development analysis. A decision was made to obviate those fields which have no relevance for this comparative study, either because they provide hardly any or no information or due to their quick mismatch with reality (price, date and authorship of the analysis). This analysis has been carried out taking into account not to fall into the errors of misconduct in the research, and hence very care has been taken to following an ethical and rigorous guideline in the process of this research (Petousi & Sifaki, 2020).

The analysis was performed by three evaluators –the authors of this work— with experience in Early Childhood Education, especially two of them whose professional task at the university consists in training future teachers for this educational stage. The examination referred to eight floor robot models (Figs. 12.4 and 12.5) suited for their utilization with Early Childhood Education students:

1. Bee-Bot

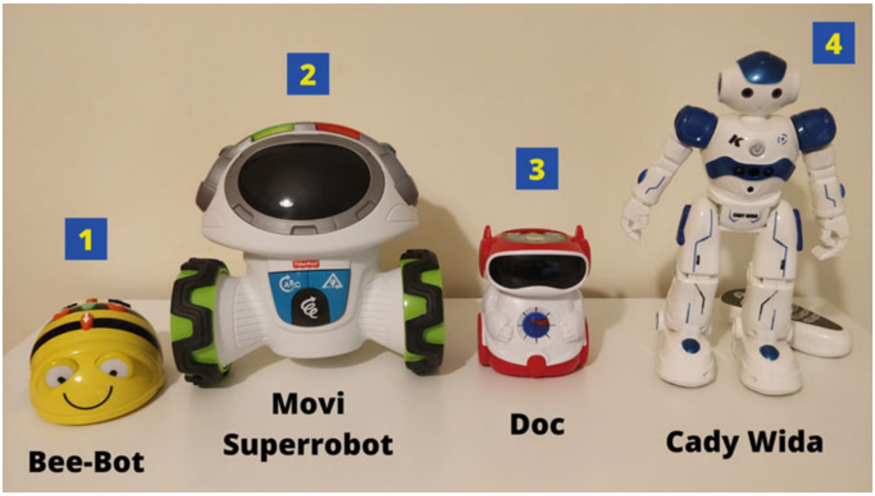


**Fig. 12.4** Robots 1 to 4: Bee-Bot, Movi Superrobot, Doc and Cady Wida

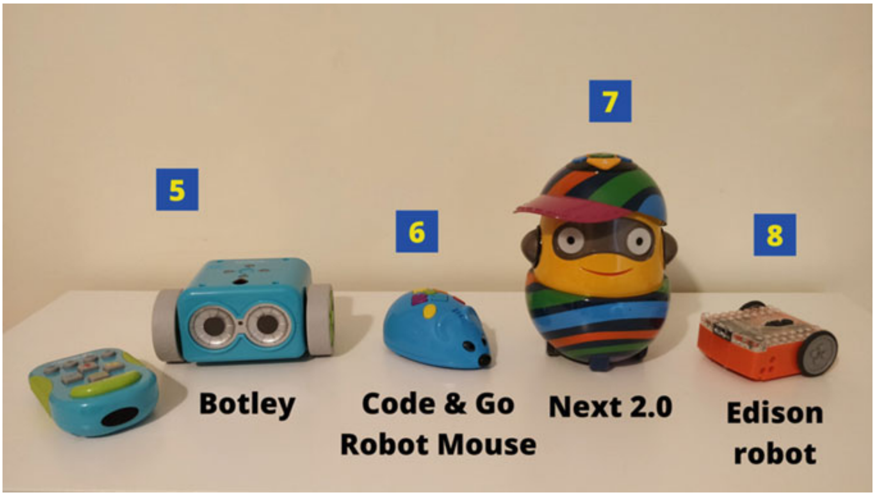


**Fig. 12.5** Robots 5 to 8: Botley, Code & Go—Robot Mouse, Next 2.0 and Edison robot

2. Movi Superrobot
3. Doc
4. Cadi Wida
5. Botley
6. Code & Go - Robot Mouse
7. Next 2.0
8. Edison robot

The choice of these eight robots was random, trying to ensure that their price was not too high and that they were easily located. We are aware of the existence of other robots that have been left out of this analysis. So, for example we can name some like Cubetto, Sphero, Matatalab, mTiny, Codey Rocky, etc. Therefore, we want to insist that we are talking about an example of the use of the FAREI tool (in another study already developed and validated) for the taxonomy and adaptation of floor robots in Early Childhood Education. Likewise, the analysis presented here has been carried out by the authors of this study, who we have been able to contemplate the characteristics of our student and our immediate environment; and thus, in each analysis that is made, it must be the teacher involved who has these premises in mind, which will be different for each teacher, classroom and educational center.

Seeking to draw a comparison between them all, a breakdown is provided of every field addressed in the FAREI card so that the process of analysis can be better understood (Álvarez-Herrero, 2021). Likewise, as anticipated above, no attention was paid to those characteristics which may have a more local nature or lack validity in this comparative study, amongst them fields such as price, language/s in which the instructions are written, authorship of the analysis or date thereof, to quote but a few. And we want to insist that the analysis presented here does not intend to recommend one robot or another, but that this analysis is presented as an example so that it is the teacher who, attending to their needs and the characteristics of their students and school, do analysis accordingly. It should be noted that the evaluations of the different criteria have been carried out by the authors of this study according to their criteria and personal perceptions, and the results that we show here respond to the mean value of the three researchers. Therefore, characteristics such as robustness, aesthetics, etc. which may seem difficult to measure, showing the average of the three evaluations carried out, dilute the subjectivity that may be implicit in these criteria.

Table 12.1 identifies the different models covered in this examination: names, manufacturing enterprise and/or publisher that commercializes it, and recommended ages. It is worth highlighting with regard to the last criterion that we chose robots oriented to the Early Childhood Education stage, where students' ages range between 3 and 5 years. Note also that, in order to fix these ages, consideration was given both to

**Table 12.1** Name, brand and minimum recommended age for the 8 robots under analysis

| | Name | Brand/publisher | Recommended age |
|---|---|---|---|
| 1 | Bee-Bot | TTS group | + 3 |
| 2 | Movi superrobot | Fisher-price | + 3 |
| 3 | Doc | Clementoni | + 5 |
| 4 | Cady wida | JianJian technology | + 5 |
| 5 | Botley | Learning resources | + 5 |
| 6 | Code & Go—robot mouse | Learning resources | + 4 |
| 7 | Next 2.0 | Adele robots para edelvives group | + 3 |
| 8 | Edison robot | Microbric | + 4 |

**Table 12.2** Characteristics regarding instructions, movement, optical and acoustic signals of the 8 robots examined

| | Instructions | Movement | Optical signals | Audio |
|---|---|---|---|---|
| 1 | Yes | 15 × 15 panels | Yes | Yes |
| 2 | Yes | Not controlled, 1.52 m range | Yes | Yes |
| 3 | Yes | 15 × 15 panels | No | Yes |
| 4 | Yes | Not by panels, remote-controlled | Yes | Yes |
| 5 | Yes | 20 × 20 panels | Yes | Yes |
| 6 | Yes | 12.5 × 12.5 panels | No | Yes |
| 7 | Yes | 15 × 15 panels | Yes | Yes |
| 8 | No. They have to be downloaded from the internet | Sensor-controlled/remote-controlled/by blocks | Yes | Yes |

the manufacturer's opinion and to that of the firms commercializing the models and, above all, to the evaluator's view. The discrepancy which may have arisen between the ages determined by each one of them only appeared in a couple of cases and with a difference of only 1 or 2 years.

Since detailed descriptions of the models analyzed can be found on the websites of the different manufacturers, it seems more interesting for us to focus on other aspects in this analysis. Table 12.2 groups together a series of important characteristics featured by the floor robots under study: whether they have available instructions for their use; how they perform their movements; and whether they emit optical signals (lights and/or sparkles) and acoustic signals (sound, music, audios). As shown in Table 12.2, they all include instructions except for Edison robot, for which they can be downloaded from the manufacturer's website. There we can find more resources and tutorials about the utilization and operation of this robot. As for movement, most of them move by panels, though of various sizes, the most common one being that of 15 × 15 cm, which can be found in three cases: Bee-Bot, Doc and Next 2.0. They all emit acoustic signals too and only two of them do not emit any optical signals.

In the following blocks of characteristics examined (Table 12.3), a comparison is made between two key aspects worth taking into account in these robots considering the peculiarities of learners in this Early Childhood Education stage, amongst which stand out aesthetics and robustness. They are both assessed on a scale from 0 (very little or deficient) to 5 (very good or excellent). Thus, concerning aesthetics, we checked whether robots have an appealing appearance that can catch students' attention and whether the possibility is offered to tune or customize those robots with own or supplementary decoration that might eventually be acquired. Robustness has to do with these robots' consistency and resistance to blows, falls… which are highly frequent throughout this stage. The material with which the robots have been manufactured also becomes essential, since the type of plastic used can make

**Table 12.3** Characteristics about the aesthetics, robustness, power and life of the 8 robots under analysis

| | Aesthetics | Robustness | Batteries/recharge | Life |
|---|---|---|---|---|
| 1 | 5 | 5 | Rechargeable battery | 8 h |
| 2 | 5 | 5 | 4 1.5 V (LR14) batteries | 6–6.5 h |
| 3 | 5 | 5 | 3 1.5 V (LR6) batteries | 5–7 h |
| 4 | 5 | 3 | Rechargeable battery in the robot and 2 1.5 V (LR6) batteries in the remote control | 1 h |
| 5 | 4 | 4 | 3 + 2 1.5 V (LR03) batteries | 4 h |
| 6 | 4 | 4 | 3 1.5 V (LR03) batteries | 4 h |
| 7 | 5 | 5 | Rechargeable battery | 6 h |
| 8 | 3 | 3 | 4 1.5 V (LR03) batteries | 5 h |

them more or less robust. Table 12.3 also lists the power that they need to stay in motion, as well as the life or duration of their batteries or charge, in a normal use.

As can be verified, manufacturers paid quite a lot of attention to these aspects of aesthetics and robustness, thus taking into consideration potential users of these robots. More precisely, four models fully comply with these premises, namely: Bee-Bot, Movi Superrobot, Doc and Next 2.0. In turn, regarding the use of batteries or charge, recharging internal batteries seems more suitable to us, since this procedure makes it unnecessary to unscrew or access a robot compartment in order to change its batteries. In terms of battery life, it is fair to say that the amounts specified are those established for a standard use of the robot and, moreover, that they drastically decrease if robots are utilized on a continued basis. Thus, for instance, in the case of Bee-Boot, its life reaches 8 h in a normal use, whereas a continued use reduces that duration to only 2 h.

Furthermore, we thought it was important to compare the aspects associated with the programming of robots (see Table 12.4): what type of programming governs them (by blocks, code, scratch…), the maximum number of commands or orders which can be given to them; and where the robot is programmed from. Considering the ages to which these robots are aimed, one could expect a type of programming focused on programming by blocks or panels following a set or orders or commands. Two striking cases identified deserve a special mention in this regard. On the one hand, Movi Superrobot is not governed by programming. Although it experiences movement and an interaction exists with the boy or the girl, the movement has an arbitrary as well as random nature, and the interaction is confined to answering dichotomous questions that the robot launches by pressing one button illuminated green or another illuminated red. On the other hand, although its programming is indicated by reading barcodes of predefined programs (follow the light, follow the line, avoid obstacles…) for Early Childhood Education, the Edison robot provides a possibility for older ages, with the chance of programming either by blocks or by code (Phyton).

**Table 12.4** Programming-related characteristics of the 8 robots examined

| | Type of programming | Maximum no. of orders | Where is it programmed from? |
|---|---|---|---|
| 1 | Commands/blocks | 40 | Manual, from inside the robot itself |
| 2 | It has none | – | – |
| 3 | Commands/blocks | 25 | Manual, from inside the robot itself |
| 4 | Commands | 50 | Remote control |
| 5 | Commands/blocks | 80 | Remote control |
| 6 | Commands/blocks | 40 | Manual, from inside the robot itself |
| 7 | Commands/blocks | 40 | Manual, from inside the robot itself |
| 8 | Predefined programs/blocks | – | With barcodes, from a remote control, or from a smartphone or tablet with apps |

With respect to the maximum number of orders or commands that robots programmed in this way can obey, it turns out that they range between 25 in Doc and 80 in Botley, the most usual number being the figure of 40 corresponding to Bee-Bot, Code & Go—Robot mouse, and Next 2.0. Most of them are also programmed from inside the robot itself, this being the most convenient, accessible and suitable option for Early Childhood Education students; however, some are programmed using a remote control, as exemplified by Cady Wida and Botley. As for Edison robot, it permits both a predefined programming from barcodes, like being governed from remote controls, and programming it by blocks and code through apps for Tablets and Smartphones.

An important concern when it comes to the use of floor robots in the training of Early Childhood Education learners refers to whether they allow for the development of various competences and skills. Thus, all the models programmed via commands and by blocks (Bee-Bot, Doc, Botley, Code & Go—Robot Mouse and Next 2.0), offer the possibility to develop a wide range of competences, including:

- Generate motivation and interest in learning.
- Promote interaction, debate and communication.
- Allow feedback (feedback-based learning—self-correction of errors).
- Develop initiative and personal autonomy as well as creativity.
- Provide training in problem solving and learning to learn.
- Develop critical, analytical, logical and computational thinking.
- Encourage collaborative work.
- Develop spatial sight and distance judgment.

In addition to this group, there are another three robot models which, despite offering some interesting features, are nothing but rather incomplete options, since they do not permit the development of the wide range of competences and skills described above. By way of example, students find Movi Superrobot and Cady Wida very appealing because of their movements and sounds. These robots favor play, the enhancement of critical thinking, oral comprehension, following instructions and performing movements. In turn, Edison robot is very complete with plenty of options, though it seems to have been conceived for other ages. The chances that it offers in Early Childhood Education are very limited and rather oriented towards games and discovery.

Table 12.5 below shows the assessments corresponding to the difficulty in assembling or using the different robots on a scale from 0 (none) to 5 (very high). It likewise highlights some of the advantages and drawbacks brought by these robots. Concerning assembly, no robots feature any difficulty whatsoever, as all of them come already assembled. Only Movi Superrobot needed to put together the mobile foot or support after its unpacking. Changing batteries or recharging them does require an adult's supervision. And in terms of their operation, five models are very user-friendly and intuitive because they have on them the buttons which allow for their programming or for interaction. By contrast, there are others whose movements are governed from a remote control (Cady Wida and Botley) or require reading barcodes (Edison robot). As for advantages and drawbacks, due to the peculiarities of each model, we refer the readers back to Table 12.5 so that they can know those advantages and drawbacks in detail. Always remembering that they are the particular perceptions of the authors of this study, and that there will be other teachers who to the disadvantages that are seen here, for them are advantages.

Finally, Table 12.6 shows the final assessment and the value for money of the 8 models examined. As for the final assessment, with a scale from 0 (very bad) to 5 (very good), it was carried out on a consensus basis amongst evaluators at the end of the process. Concerning value for money, it was established from the average market price and the final assessment given to them. Thus, a high value suggests that the features displayed are in tune with the price at which the robot in question can be acquired; a medium value means that a mismatch exists, either because the price is high considering the functions that it offers or because, despite having a moderate or adjusted price, it does not offer the possibilities that it should; and a low value implies that no balance whatsoever exists between the quality provided and the price of the robot.

## 12.5 Conclusions

By way of conclusion, and after having described and analyzed the 8 robot models proposed, it seems necessary for us to specify those premises or characteristics that the model or models chosen for Early Childhood Education should have, without expressing a preference for one model or another. These are premises that we consider can help teachers decide on which floor robot to use with their students. At no time do we intend to choose, recommend or express our preference for one or the other.

**Table 12.5** Characteristics related to difficulty in assembly and operation, together with the advantages and drawbacks of the 8 robots under analysis

| | Difficulty in assembly for students | Difficulty in operation for students | Advantages | Drawbacks |
|---|---|---|---|---|
| 1 | 0 | 0 | Simplicity<br>Intuition<br>Aesthetics<br>It is possible to generate mats, disguises for the robot, etc. on an open-source, free basis | Battery duration with a continued use (2 h)<br>Movement error of ±8 mm<br>Separate accessories can be bought |
| 2 | 0 | 0 | Simplicity<br>Aesthetics<br>It promotes oral comprehension | Movi superrobot communicates in a single language, without the possibility to incorporate others or change to them<br>It launches oral questions to be answered by pressing a button on the robot, which makes its functionality and applicability highly limited |
| 3 | 0 | 0 | Three possible operation modes: free; edu; and game | Doc communicates in a single language, without the possibility to incorporate Others or change to them<br>The edu and game modes are limited to the boards that go with the robot |
| 4 | 0 | 3 | It can be controlled with gestures<br>It has various modes: demo, patrol, dance, music, program and mechanical dance | Cady Wida communicates in a single language, without the possibility to incorporate others or change to them<br>The movements and sequences of these programs are quite imprecise |

(continued)

**Table 12.5** (continued)

| | Difficulty in assembly for students | Difficulty in operation for students | Advantages | Drawbacks |
|---|---|---|---|---|
| 5 | 0 | 2 | It comes with many complements. Able to detect objects and to follow a black line | Duration of batteries. It is not possible to use several at the same time; all of them are operated with remote controls |
| 6 | 0 | 0 | You can buy it with many complements | Little robustness. It usually experiences operation problems after being used for a certain time. Scarce battery life |
| 7 | 0 | 0 | It permits programming from an App which is installed on a mobile or tablet | It has operation problems (movement, connection for battery charge…) |
| 8 | 0 | 3 | They have a modular nature and can be expanded with Lego blocks, in addition to combining with other edison robots. It permits programming by blocks, by means of Scratch and using Phyton code<br>We can start using it in early childhood education and continue to use it in primary education and later in secondary education | The teacher's guidance and orientation are needed at all times. The most feasible option in early childhood education is either to program it by means of barcodes or to operate it from a remote control (not all TV or DVD remote control models are compatible) |

Thus, in our opinion, the robot ought to have the characteristics listed below in order to be selected:

- Rechargeable better than with conventional, non-rechargeable batteries
- With accessories or the possibility to create them on an open-source basis
- With buttons directly operated on the robot
- Great robustness and attractive aesthetics for a boy or a girl
- A good number of orders, but ensuring that they can work
- Movement by panels
- Without the need to assemble and user-friendly
- With optical and acoustic signals

**Table 12.6** Final assessment and value for money of the 8 robots under study

| | Name | Final assessment | Value for money |
|---|---|---|---|
| 1 | Bee-Bot | 5 | High |
| 2 | Movi superrobot | 1 | Medium |
| 3 | Doc | 4 | High |
| 4 | Cadi wida | 2 | Medium |
| 5 | Botley | 4 | High |
| 6 | Code & Go—robot mouse | 4 | Medium |
| 7 | Next 2.0 | 4 | Low |
| 8 | Edison robot | 3 | High |

– The recommended age should cover the whole Early Childhood Education stage from 3 to 5 years of age
– It must allow for the development of competences and skills, especially the implementation of computational thinking, logical thinking, critical thinking, with the ability for learning to learn and, apart from making personal autonomy enhancement possible, it should in turn permit teamwork.
– Formulate the guideline for the decision process as follows: a) think about… (the competence level of …, the frequency of use…); b) take into account… (your methodology/didactics approach…, the usability of…,); c) don't forget…

Some of these characteristics coincide with those detected in research similar to ours (Catlin et al., 2018, 2019; Papadakis, 2020), although, as we have already indicated, these studies only establish criteria for their classification and taxonomy, without establishing criteria for the quality and suitability of the use of these robots in Early Childhood Education, which our study does establish.

We would additionally like to highlight that these premises have been defined so that local issues remain aside, seeking to ensure that they are valid for whatever context and reality. Nonetheless, due to the vertiginous evolution of technology and the pace at which it changes, more up-to-date floor robots, with a wider range of features and better suited to the learning of Early Childhood Education students, are very likely to appear shortly. This forces the teacher to stay aware of any changes and innovations which may take place, as well as to be committed to permanent learning (Casey et al., 2021; Castro et al., 2018).

We also want to stress again that the choice of one or another robot not only must rely on the aforesaid premises but also take into consideration the context, the possibilities, the singularity of each classroom or educational center, as well as the students belonging to the classroom or center in question. In order to achieve that aim, the teacher or teachers in charge of those groups are the ideal persons to analyze and choose the most suitable model for each case (Camilleri, 2017).

The premises that we offer here after having studied and examined 8 floor robot models for Early Childhood Education learners under a STEM perspective must provide guidance and orientation both for their analysis and for their choice. None of the above excludes the need for Early Childhood Education teachers to be trained in the concepts and methodology required to implement computational thinking and educational robotics in their classrooms. This will make it possible to ensure not only a good selection of these resources but also their proper use in the classroom. Furthermore, such training must be received both by the practicing teachers and by the future teachers at university.

We agree with the Velentza et al. (2021) study in that it is preferable that the teacher can interact and work with the robot previously, in order to make informed decisions and not only on paper, about which robot is the most appropriate for their students. A good choice of the educational robot to use guarantees the learning and development of different competences and abilities, even in a speech therapy clinic it can achieve in its students, that they develop and master the knowledge in programming and algorithmic thinking and also the development of communication abilities (Chaldi & Mantzanidou, 2021).

As a final conclusion, it is worth highlighting that this chapter lays the foundations for an initial approach and examination of the various floor robot models available in the market for us to implement educational robotics and computational thinking in Early Childhood Education classrooms based on a STEM perspective. This process of analysis resulted in a number of valid and conclusive premises or recommendations which can help other teachers when they have to choose these robots thinking about their centers and their students.

## References

Álvarez-Herrero, J. F. (2019). Interés por la robótica y el pensamiento computacional entre el futuro profesorado de educación infantil. In *Conference proceedings EDUNOVATIC 2019* (pp. 53–57). Redine. http://bit.ly/roboINF

Álvarez-Herrero, J. F. (2020). Computational thinking in early child-hood education, beyond floor robots. *Education in the Knowledge Society (EKS),* 21, 1–11. https://doi.org/10.14201/eks.22366

Álvarez-Herrero, J. F. (2021). Design and validation of an instrument for the taxonomy of floor robots in early childhood education. *Pixel-Bit. Revista de Medios y Educación*, 60, 59–76. https://doi.org/10.12795/pixelbit.78475

Angeli, C. (2021, March). An interaction effect between gender and scaffolding strategy during an intervention about how to teach young learners to think computationally with a floor programmable robot. In *Society for information technology & teacher education international conference* (pp. 1–6). Association for the Advancement of Computing in Education (AACE). https://www.learntechlib.org/primary/p/219348/

Arnott, L., Palaiologou, I., & Gray, C. (2019). An ecological exploration of the internet of toys in early childhood everyday life. In G. Mascheroni, & D. Holloway (Eds.), *The internet of toys. Studies in childhood and youth* (pp. 135–157). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-10898-4_7

Bers, M. U. (2008). Using robotic manipulatives to develop technological fluency in early childhood. In O. N. Saracho & B. Spodek (Eds.), *Contemporary perspectives on science and technology in early childhood education* (pp. 105–125). Information Age Publishing Inc.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145–157. https://doi.org/10.1016/j.compedu.2013.10.020

Bers, M. U., Ponte, I., Juelich, C., Viera, A., & Schenker, J. (2002). Teachers as designers: Integrating robotics in early childhood education. *Information Technology in Childhood Education Annual*, 2002(1), 123–145. https://www.learntechlib.org/primary/p/8850/

Bers, M., Seddighin, S., & Sullivan, A. (2013). Ready for robotics: Bringing together the T and E of STEM in early childhood teacher education. *Journal of Technology and Teacher Education, 21*(3), 355–377. https://www.learntechlib.org/primary/p/41987/

Caballero, Y. A., & García-Valcárcel, A. (2018, October). A robotics-based approach to foster programming skills and computational thinking: Pilot experience in the classroom of early childhood education. In *Proceedings of the sixth international conference on technological ecosystems for enhancing multiculturality* (pp. 41–45). https://doi.org/10.1145/3284179.3284188

Camilleri, P. (2017). Minding the gap. Proposing a teacher learning-training framework for the integration of robotics in primary schools. *Informatics in Education, 16*(2), 165–179. https://doi.org/10.15388/infedu.2017.09

Casey, J. E., Gill, P., Pennington, L., & Mireles, S. V. (2018). Lines, roamers, and squares: Oh my! using floor robots to enhance Hispanic students' understanding of programming. *Education and Information Technologies, 23*(4), 1531–1546. https://doi.org/10.1007/s10639-017-9677-z

Casey, J. E., Pennington, L. K., & Mireles, S. V. (2020). Technology acceptance model: Assessing preservice teachers' acceptance of floor-robots as a useful pedagogical tool. *Technology, Knowledge and Learning.* https://doi.org/10.1007/s10758-020-09452-8

Casey, J. E., Pennington, L. K., & Mireles, S. V. (2021). Technology acceptance model: Assessing preservice teachers' acceptance of floor-robots as a useful pedagogical tool. *Technology, Knowledge and Learning, 26*, 499–514. https://doi.org/10.1007/s10758-020-09452-8

Castro, E., Cecchi, F., Salvini, P., Valente, M., Buselli, E., Menichetti, L., Calvani, A., & Dario, P. (2018). Design and impact of a teacher training course, and attitude change concerning educational robotics. *International Journal of Social Robotics, 10*, 669–685. https://doi.org/10.1007/s12369-018-0475-6

Catlin, D., Kandlhofer, M., Holmquist, S., Csizmadia, A. P., Angel-Fernandez, J., & Cabibihan, J. (2018). Edurobot taxonomy and Papert's Paradigm. *Constructionism, 2018*, 151–159.

Catlin, D., Kandlhofer, M., Cabibihan, J. J., Angel-Fernandez, J., Holmquist, S., & Csizmadia, A. P. (2019). EduRobot taxonomy. In L. Daniela (Ed.), *Smart learning with educational robotics* (pp. 333–338). Springer. https://doi.org/10.1007/978-3-030-19913-5_15

Çetin, M., & Demircan, H. Ö. (2020). Empowering technology and engineering for STEM education through programming robots: A systematic literature review. *Early Child Development and Care, 190*(9), 1323–1335. https://doi.org/10.1080/03004430.2018.1534844

Chaldi, D., & Mantzanidou, G. (2021). Educational robotics and STEAM in early childhood education. *Advances in Mobile Learning Educational Research, 1*(2), 72–81. https://doi.org/10.25082/AMLER.2021.02.003

Dongming, L., Wanjing, L., Shuang, C., & Shuying, Z. (2020, March). Intelligent robot for early childhood education. In *Proceedings of the 2020 8th international conference on information and education technology* (pp. 142–146). https://doi.org/10.1145/3395245.3396420

Elkin, M., Sullivan, A., & Bers, M. U. (2014). Implementing a robotics curriculum in an early childhood montessori classroom. *Journal of Information Technology Education: Innovations in Practice*, 13, 153–169. http://www.jite.org/documents/Vol13/JITEv13IIPvp153-169Elkin882.pdf

Fislake, M. (2018). Robotics in technology education. In M. de Vries (Ed.), *Handbook of technology education. Springer international handbooks of education* (pp. 361–384). Springer. https://doi.org/10.1007/978-3-319-44687-5_28

Fislake, M. (2022). Educational robotics between coding and engineering education. In I. Management sssociation (Eds.), *Research anthology on computational thinking, programming, and* *robotics in the classroom* (pp. 824–857). IGI Global. https://doi.org/10.4018/978-1-6684-2411-7.ch036

Fridberg, M., & Redfors, A. (2021). Teachers' and children's use of words during early childhood STEM teaching supported by robotics. *International Journal of Early Years Education*. https://doi.org/10.1080/09669760.2021.1892599

García-Valcárcel, A., & Caballero-González, Y. (2019). Robotics to develop computational thinking in early childhood education. [Robótica para desarrollar el pensamiento computacional en Educación Infantil]. *Comunicar, 59*, 63–72. https://doi.org/10.3916/C59-2019-06

Glezou, K. V. (2020). Fostering computational thinking and creativity in early childhood education: Play-learn-construct-program-collaborate. In S. Papadakis, & M. Kalogiannakis (Eds.), *Mobile learning applications in early childhood education* (pp. 324–347). IGI Global. https://doi.org/10.4018/978-1-7998-1486-3.ch016

Greca, I. M., García, E., Fridberg, M., Cronquist, B., & Redfors, A. (2020). Robotics and early-years STEM education: The botSTEM framework and activities. *European Journal of STEM Education*, 1, 1–13. https://doi.org/10.20897/ejsteme/7948

Hamilton, M., Clarke-Midura, J., Shumway, J. F., & Lee, V. R. (2020). An emerging technology report on computational toys in early childhood. *Technology, Knowledge and Learning, 25*(1), 213–224. https://doi.org/10.1007/s10758-019-09423-8

Ioannou, A., & Makridou, E. (2018). Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work. *Education and Information Technologies, 23*(6), 2531–2544. https://doi.org/10.1007/s10639-018-9729-z

Kalogiannakis, M., Tzagkaraki, E., & Papadakis, St. (2021). A Systematic Review of the Use of BBC Micro:bit in Primary School. In *Proceedings of the 10th Virtual Edition of the International Conference New Perspectives in Science Education* (pp. 379–384). https://doi.org/10.26352/F318_2384-9509

Kalogiannidou, A., Natsiou, G., & Tsitouridou, M. (2021). Robotics in early childhood education: Developing a framework for classroom activities. In S. Papadakis, & M. Kalogiannakis (Ed.), *Handbook of research on using educational robotics to facilitate student learning* (pp. 402–423). IGI Global. https://doi.org/10.4018/978-1-7998-6717-3.ch016

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 41*(4), 245–255. https://doi.org/10.1007/s10643-012-0554-5

Di Lieto, M. C., Inguaggiato, E., Castro, E., Cecchi, F., Cioni, G., Dell'Omo, M., Laschi, C., Pecini, C., Santerini, G., Sgandurra, G., & Dario, P. (2017). Educational robotics intervention on executive functions in preschool children: A pilot study. *Computers in Human Behavior, 71*, 16–23. https://doi.org/10.1016/j.chb.2017.01.018

Lieto Di, M. C., Pecini, C., Castro, E., Inguaggiato, E., Cecchi, F., Dario, P., Sgandurra, G., & Cioni, G. (2019). Robot programming to empower higher cognitive functions in early childhood. In L. Daniela (Ed.), *Smart learning with educational robotics* (pp. 229–250). Springer. https://doi.org/10.1007/978-3-030-19913-5_9

Meadows, M., & Rodney, B. (2021). Playful robotics and meaningful learning in early childhood education. In E. Langran, & L. Archambault (Eds.), *Proceedings of society for information technology & teacher education international conference* (pp. 1052–1056). https://www.learntechlib.org/primary/p/219256/

Olabe, J., Basogain, X., Olabe, M., Maíz, I., & Castaño, C. (2014). Solving math and science problems in the real world with a computational mind. *Journal of New Approaches in Educational Research, 3*(2), 75–82. https://doi.org/10.7821/naer.3.2.75-82

Papadakis, S. (2020). Robots and robotics kits for early childhood and first school age. *International Association of Online Engineering*. https://doi.org/10.3991/ijim.v14i18.16631

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences, 11*(5), 204. https://doi.org/10.3390/educsci11050204

Papadakis, S., & Kalogiannakis, M. (2020). Exploring preservice teachers' attitudes about the usage of educational robotics in preschool education. In *Handbook of research on tools for teaching computational thinking in P-12 Education* (pp. 335–351). IGI Global. https://doi.org/10.4018/978-1-7998-4576-8.ch013

Patiño-Escarcina, R. E., Barrios-Aranibar, D., Bernedo-Flores, L. S., Alsina, P. J., & Gonçalves, L. M. G. (2021). A methodological approach to the learning of robotics with EDUROSC-kids. *Journal of Intelligent & Robotic Systems, 102*, 1–23. https://doi.org/10.1007/s10846-021-01400-7

Petousi, V., & Sifaki, E. (2020). Contextualizing harm in the framework of research misconduct. Findings from discourse analysis of scientific publications. *International Journal of Sustainable Development, 23*(3/4), 149–174. https://doi.org/10.1504/IJSD.2020.10037655

Reinking, A., & Martin, B. (2018). The gender gap in STEM fields: Theories, movements, and ideas to engage girls in STEM. *Journal of New Approaches in Educational Research, 7*(2), 148–153. https://doi.org/10.7821/naer.2018.7.271

Román-Graván, P., Hervás-Gómez, C., Martín-Padilla, A. H., & Fernández-Márquez, E. (2020). Perceptions about the use of educational robotics in the initial training of future teachers: A study on steam sustainability among female teachers. *Sustainability, 12*(10), 4154. https://doi.org/10.3390/su12104154

Roussou E., & Rangoussi M. (2020). On the use of robotics for the development of computational thinking in kindergarten: Educational intervention and evaluation. In M. Merdan, W. Lepuschitz, G. Koppensteiner, R. Balogh, & D. Obdržálek (Eds.), *Robotics in education. RiE 2019. Advances in intelligent systems and computing* (pp. 31–44). Springer. https://doi.org/10.1007/978-3-030-26945-6_3

Tzagkaraki, E., Papadakis, St., & Kalogiannakis, M. (2021). Exploring the use of educational robotics in primary school and its possible place in the curricula. In M. Malvezzi, D. Alimisis, & M. Moro (Eds.), *Education in & with robotics to foster 21st century skills. Proceedings of EDUROBOTICS 2020* (pp. 216–229). https://doi.org/10.1007/978-3-030-77022-8_19

Velentza, A. M., Pliasa, S., & Fachantidis, N. (2021). Future teachers choose ideal characteristics for robot peer-tutor in real class environment. In A. Reis, J. Barroso, J. B. Lopes, T. Mikropoulos, & C. W. Fan (Eds.), *Technology and innovation in learning, teaching and education. TECH-EDU 2020. Communications in computer and information science* (pp. 476–491). Springer. https://doi.org/10.1007/978-3-030-73988-1_39

Vizner, M. Z. (2017). *Big robots for little kids: Investigating the role of scale in early childhood robotics kits* (order no. 10622097). Available from ProQuest dissertations & theses global. (1968621946). https://www.proquest.com/dissertations-theses/big-robots-little-kids-investigating-role-scale/docview/1968621946/se-2?accountid=17192

Zviel-Girshin, R., Luria, A., & Shaham, C. (2020). Robotics as a tool to enhance technological thinking in early childhood. *Journal of Science Education and Technology, 29*, 294–302. https://doi.org/10.1007/s10956-020-09815-x

# Chapter 13
# Teachers' Attitudes on the Use of Educational Robotics in Primary School

**Effransia Tzagaraki, Stamatios Papadakis, and Michail Kalogiannakis**

**Abstract** The increasing use of educational robotics prompted our study. The aim is to examine the attitudes of primary school teachers regarding its use in the classroom. Identifying the gap in the literature with the questionnaire developed and answered by 156 teachers at Greek primary schools. We focused on their views on the contribution of robotics in improving the learning process, the development of skills, and opportunities to enhance their involvement with robotic activities. As the results show, teachers are optimistic about its use, recognizing that it facilitates learning, is valuable and practical for teaching. They also recognize its contribution to developing technological, mathematical, social, and language skills. As educational robotics is a problematic field for most teachers to learn and apply, training is emerging.

**Keywords** Educational robotics · Teachers' attitudes · Primary school

## 13.1 Introduction

Increased research data reinforce the conclusion that integrating STEM courses in pre-school and primary school education strengthens motivation and improves learning (Scaradozzi et al., 2015; Vlasopoulou et al., 2021). Educational robotics is moving in this direction, and its animated features make young students adopt a positive attitude regarding their engagement with it and therefore are a valuable tool for introducing students to ICT concepts and developing twenty-first century skills (Alimisis, 2013).

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Educational robotics is enhanced to increase students' interest in STEM education and other fields such as arts and languages (Chalmers, 2017). In this sense, engaging in robotics increases learning opportunities. Moreover, while robotics's reputation and benefits are rising, its integration into the primary school curriculum is limited. According to the literature, there are several reasons for this restriction in its use. Some of these are the lack of appropriate educational material, the cost of robots, the lack of teaching time, and limited knowledge about its advantages (Negrini, 2020).

Thus, a study of the primary users, the teachers, are needed to enhance its use. The shaping and enrichment of school curricula with appropriate teaching methods and training will contribute to teachers' positive attitudes (Negrini, 2020). Existing curricula include teaching concepts related to science and mathematics but not teaching problem-solving, computer science, technology, and robotics (Scaradozzi et al., 2015).

Research data show that student-teacher interaction is a critical element in learning. Furthermore, more specifically for our study, teachers' attitudes of teaching and learning robotics affect the practices used and possibly affect the respective perceptions of students. By recognizing the critical role of these attitudes in shaping their behavior, teachers can successfully integrate robotics into their practice and improve the quality of teaching. However, we could not ignore the complexity of mental processes such as teachers' beliefs (Pajares, 1992).

As it emerges, there is a lack of research on the perceptions and attitudes of primary school teachers about the use of robotics in the classroom (Negrini, 2020) and, therefore, the need for further investigation. The present research seeks to fill this gap and highlight new data in the existing literature by exploring primary school teachers' perceptions of educational robotics and its integration into the school curriculum. It is a quantitative study, and the data is derived from an 11-item questionnaire. Initially, the term educational robotics is defined, the terms attitude and perception of teachers in general and attitudes for educational robotics, in particular, are clarified. Then, the purpose and research questions, the method, and the main results were described. The main conclusions are presented at the end.

## 13.2 Educational Robotics

The history of robotics has its origins in the Logo programming language (1970) and has become a useful pedagogical and educational tool. At the core of educational robotics are the theories of constructivism (Piaget), constructionism (Papert), socio- constructivism (Vygotsky), and discovery learning (Bruner) (Piedade et al., 2020). The contribution of these perspectives lies in a clearer understanding of the individual's experiences and interactions with the outside world (Ackermann, 2001).

The use of educational robotics has evolved rapidly over the last 20 years in all age groups. Robotics is now part of school programs and extracurricular programs such as clubs and summer camps to strengthen students' individual and professional skills (Anwar et al., 2019). However, there is a lack of studies on its use for students aged 6–12 (Kyriazopoulos et al., 2021).

This study uses educational robotics to refer to activities where students engage in simple robots connected to electronic systems. Robots are programmed to perform a task, and data is detected through the integrated or connected sensors based on the programming of the microcontroller or processor. With such activities, students must solve real problems by combining programming and coding with motors, using their imagination, algorithmic thinking, and other skills to produce their projects (Guven & Cakir, 2020). As it appears from the literature, such tools are helpful as they contribute to enhancing students' interest and motivation and acquiring knowledge and skills related to various courses (Di Battista et al., 2020).

Most of the research that has been done on the use of educational robotics finds positive results and many capabilities in enhancing students' and teachers' skills (to a greater extent, it is considered that students are favored) and the learning context in general (Choi et al., 2019; Faisal et al., 2012; Negrini, 2020; Piedade et al., 2020). However, cases where the expected positive results in learning from engaging in robotic activities have not been noted (Di Battista et al., 2020). There seems to be a positive relationship from using this innovative tool with the cultivation of computational thinking, problem-solving and decision-making ability, algorithmic thinking, divergent thinking, creativity, and collaboration, due to its animated features and its connection to various other subjects (Alimisis, 2013).

Using educational robotics in the classroom, the teacher can respond more effectively to the different needs of their students. Compared to other information and communication technologies (ICT) such as interactive whiteboards, robotics creates a different learning method. The student manages a physical device from the assembly and programming stage to the final operation. Students experience the need to think, review, collaborate, and communicate to solve a problem or activity (Di Battista et al., 2020). These conditions make it necessary to use robotics in the classroom.

## 13.3 Conceptual Clarifications: Teacher's' Attitudes—Perceptions

Attitude is defined as a mentality, a tendency of a person to act related to their experience and temperament. Attitudes are a complex network of beliefs, values, attitudes, and motivations of the individual (Bergman, 1998); while talking about one's attitude, we focus on his feelings and behavior (Pickens, 2005, p. 44). For example, the study of a teacher's attitude towards educational robotics includes their view on the topic (thought), their feelings about this topic (emotion), and their actions (behaviors). Beliefs and feelings may be internal elements of the personality and two of the three essential components of an attitude; however, their attitude is externalized in their behavior. These elements were considered during the development of our research tool.

Attitudes and social environment interact. In practice, this means that experiences influence attitudes to a greater or lesser degree, which means that they can change (Bergman, 1998; Pickens, 2005). This element reinforces the importance of research such as this one.

It is understood that an exhaustive analysis of the respondents' attitudes about robotics (as well as the study of attitudes in general) is impossible; however, what is sought is a study as deep as possible (Bergman, 1998). In a case like ours where we want to study attitudes, we must consider the cognitive and evaluative processes of the respondents. So, to explore deeper aspects, we included questions that examine how participants perceive the contribution of robotics and, at the same time, how they classify their thoughts (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree). This way, we will distinguish elements they consider more important and study the participants' degree of agreement or disagreement in combination with various demographic, social, or other aspects of research interest.

Perception is defined as the process of interpreting stimuli or situations by an individual based on personal experiences. This process includes the stages of "stimulation", "registration", "organization" and "interpretation". Interestingly, in this case, a person's perception of a situation or stimulus may be quite far from reality due to the subjective dimension given. There is a subjective control over what we perceive related to our ability to embrace new stimuli based on pre-existing thoughts (Pickens, 2005).

Perceptions that each of us has about the learning process, the acquisition of knowledge and experience, and how these can occur in practice influence the attitudes and practices chosen, whether by parents, educators, or even researchers. These perceptions guide our behavior (Ackermann, 2001; Pajares, 1992).

Studying the relationship between human attitudes and emotions and their behavior towards robots is not a new research field (Nomura et al., 2008; Pickens, 2005). Despite this, the teachers' acceptance and application of robotics in the classroom seem to be done slowly (Negrini, 2020). Teachers appear to resist what can be applied in the classroom concerning robotics promises. It also seems to need to connect the theoretical basis of robotics' use with its application (Camilleri, 2017).

## 13.4 Teachers' Attitudes on the Use of Educational Robotics

To make the best use of robotics and its applications in the classroom, the views of potential immediate users, who are none other than teachers and students, are fundamental (Alimisis, 2019). Their proposals should be considered equally important (Reich-Stiebert & Eyssel, 2016) because the teaching practice is improved (Pajares, 1992). In other words, in our case, the investigation and understanding of teachers' perceptions of educational robotics are essential in finding pedagogical strategies and ways to use their resources and technical skills to maximize learning effectiveness

(Choi et al., 2019). On the other hand, such an investigation is expected to highlight teachers' concerns or other difficulties and barriers that will provide critical direction for solutions and improve the acceptance of robotics (Reich-Stiebert & Eyssel, 2016).

Factors that can positively influence perceptions of educational robotics are the simplicity of a robot and ease of use that does not require specialized technical skills or knowledge. This applies to both students and teachers. It is noted in the literature that with some kind of brief introductory training for relevant concepts and programs, teachers can feel more confident and look for ways to integrate robotics without much support (Di Battista et al., 2020).

Essential parameters for recognizing the contribution of robotics to teaching and learning are reducing negative attitudes by teachers, the cost and time required to manage robots, the lack of experience and technical knowledge (Kim & Lee, 2016; Negrini, 2020). In addition, in cases where a training program was implemented, the teachers highlighted the importance of utilizing more time to practice programming and coding applications and organizing activities that will help them implement robotic activities in practice (Guven & Cakir, 2020).

Remarkable are the results of Khanlari's and Kiaie's (2015) research where, studying teachers' perceptions, they found that while the most significant percentage of participants (about 90%) know about robotics, they avoid its use due to anxiety. In the same research, it is interesting that a sizable percentage (about 36%) of the respondents do not consider integrating robotics in primary school curricula practical. In this case, students' age is deemed inappropriate for understanding the relevant knowledge and procedures.

The importance of the teacher's perceptions for the student's attitude towards school and robotics is recognized in creating the ROBOESL Project. An effort was made to strengthen teachers' technical and pedagogical skills in using robotic technologies to create original and innovative interventions (Alimisis, 2019).

Once the contribution of robotics to teaching and learning is recognized, it alone cannot bring the desired results. For the integration of robotic activities to be successful, an appropriate learning context and the selection of appropriate teaching methodologies are required. Furthermore, here is the importance of the role of the teacher Atmatzidou and Demetriadis (2017).

Appropriate robotics kits and project-based learning activities allow the teacher to engage students actively. There are such activities that robotics can be an exciting experience and enhance students' interest in STEM lessons and essential skills (computational thinking, problem-solving, collaboration, creativity, etc.) (Chiazzese et al., 2019; Faisal et al., 2012). Teachers need to understand the contribution of education as a useful tool either in teaching or learning, even for students with special needs or other learning difficulties or disorders (Battista et al., 2020).

As Sapounidis and Alimisis (2020) aptly conclude, to design successful guidance, the cognitive function must first be understood to adjust the students' cognitive load to low levels. At the same time, the teacher's advice should be guided by the status of the students as there are beginners and more experienced, in combination with the degree of difficulty presented by the new knowledge and the sought skills. Student guidance should be gradually reduced as more experience is gained. Students encountering robotics need more support than the more experienced ones for the first time. In any case, what is required is the adaptation and adjustment of the didactic guidance.

Another crucial element is designing activities adapted to the developmental level of the students. Finally, the question is not how robotics will be included in the teaching but how the teachers will use real-life situations familiar to the students. The total replacement of traditional methods with innovative ones such as educational robotics should not be sought, but their creative interaction and effective combination (Camilleri, 2017).

Researchers have identified the positive effects that robotics has on collaboration and social interaction. However, it has also been shown that cooperation and constructive student performance are negatively affected without proper guidance (Sapounidis and Alimisis, 2020). Atmatzidou and Demetriadis (2017) propose using "collaboration scenarios" in educational robotics activities to scaffold students.

Teachers' training in robotics seems to influence their perceptions of its use in the classroom. After a relevant training intervention, the teachers have a more positive attitude towards their involvement with robotics and programming in general and consider it an exciting activity. The aim is to overcome the difficulties (e.g., the assembly of the robot, its control, its disassembly) that reinforce the negative perceptions about robotics (Kim & Lee, 2016). Focused training with suggested challenges will provide inspiration and opportunities for exploring robotic activities that can be applied in the classroom (Estivill-Castro, 2020).

## 13.5 Goal—Research Questions

This study investigates the attitudes of primary school teachers regarding the use of educational robotics in the classroom and its integration into the school curriculum. The main axes considered are educational robotics to enhance learning and skills development and the need for further training of teachers. Research questions that arise according to this aim are:

- What is the attitude of teachers towards learning through educational robotics? Can it be enhanced?
- What is the attitude of teachers to the contribution of educational robotics in the development of skills for students?
- What is the participants' attitude for the training and securing required resources in using robotics in the classroom?

## 13.6 Method

### *13.6.1 Participants*

The research involved 156 (N = 156) primary school teachers in Greece, 128 women, 26 men, and two who did not mention gender. Most of the participants are between 31 and 40 years old (54.5%), have teaching experience from 11 to 15 years, and teach all subjects to primary school students (81.6%) (Table 13.1). Snowball sampling was used to collect the sample. We identified, regardless of specialty, in-service teachers who teach in Greek primary schools, students from 6 to 12 years old. They led us to other teachers who also meet the same criteria for inclusion (Cohen et al., 2007). Most participants have a master's degree and assess their level of knowledge in ICT as satisfactory (Tables 13.2 and 13.3).

**Table 13.1** Demographic characteristics of participants

| | N | % |
|---|---|---|
| *Gender* | | |
| Male | 26 | 16.7 |
| Female | 128 | 82.1 |
| Missing (No mention) | 2 | 1.3 |
| Total | 156 | 100.0 |
| *Age group* | | |
| 22–30 | 25 | 16.0 |
| 31–40 | 85 | 54.5 |
| 41–50 | 27 | 17.3 |
| 51–60 | 19 | 12.2 |
| Total | 156 | 100.0 |
| *Teaching experience* | | |
| 0–5 | 28 | 17.9 |
| 6–10 | 20 | 12.8 |
| 11–15 | 55 | 35.3 |
| 16–20 | 27 | 17.3 |
| 21 + | 26 | 16.7 |
| Total | 156 | 100.0 |

**Table 13.2** Self-assessment of the level of knowledge in ICT

| | Unsatisfying | Moderate | Satisfactory | Excellent | Total |
|---|---|---|---|---|---|
| N | 2 | 21 | 94 | 39 | 156 |
| % | 1.3 | 13.5 | 60.3 | 25.0 | 100.0 |

**Table 13.3** Education level

| | College | Master's degree | Doctorate | Total |
|---|---|---|---|---|
| N | 55 | 93 | 8 | 156 |
| % | 35.3 | 59.6 | 5.1 | 100.0 |

### *13.6.2 Instrument—Procedure*

In this study, the evaluation is done by the quantitative method. The survey consisted of 54 questions (7 demographic questions, 42 five-point Likert scale questions, and five multiple-choice questions). All variables are nominal or ordinal. A pilot application of the questionnaire was carried out to resolve any technical issues or issues related to the content and reliability. After that, our scale consists of 49 questions (7 demographic questions and 42 five-point Likert scale questions).

This structured questionnaire was created based on the purpose and the research questions and distributed online to the teachers who completed it anonymously in May 2021 (Appendix 2). The questionnaire's logical relevance and completeness were examined to verify that all questions were answered. During the test, two participants who did not meet the criteria for participation in the research were rejected (Cohen et al., 2007).

We investigated whether gender, age, level of studies, teaching experience, employment relationship (permanent/deputy), level of knowledge in ICT are predictors of teachers' attitudes towards robotics through the developed questionnaire. At the same time, it examines which disciplines and skills are most associated with robotics and whether they would like further training in it.

The statistical analysis was performed with the IBM SPSS. To check the internal consistency, interpret the results by Cronbach's alpha. A Cronbach's alpha of 0.891 was obtained, a value higher than the generally accepted 0.700, meaning that the scale used has satisfactory internal consistency (Robson, 2002). The exploratory Factor Analysis was applied to check the validity (Appendix 2). Seven factors were selected as the most important according to the eigenvalues and the percentage of variation explained by each factor. These factors explain 70.3% of the total variance.

The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's sphericity test were used to determine the sample size and homogeneity adequacy. In our case, KMO 0,884 is considered meritorious. Also, Bartlett's test of sphericity is statistically significant ($p < 0.05$) (George & Mallery, 2003).

To assess the extent to which our data deviate from normal, we used both numerical (Skewness and Kurtosis values) and graphical methods (histogram). The following table shows the survey's mean values, standard deviations, skewness, and kurtosis (Appendix 1).

## 13.7 Results

### *13.7.1 Educational Robotics and Learning Improvement*

Most participants believe that robotics learning can become fun (93.63%) and promote students' curiosity and creativity (91%), which shows a positive attitude towards its use. The positive attitude of teachers is reinforced by their statement that educational robotics supports learning without distracting children from other experiences essential for their growth. The findings show that robotics is beneficial to the student's development and supports learning. Combined with the traditional teaching model, it facilitates it by offering various stimuli (Fig. 13.1).

We tested the teacher's attitudes regarding the effect of educational robotics on learning and teaching improvement by exploring their perceptions about its effectiveness, ease of use and acquisition, usefulness, and contribution to the most appropriate exploitation of teaching time (Fig. 13.2).

As it turns out, most participants recognize the usefulness of robotics (81.4%) to improve the efficiency and effectiveness of teaching and learning. However, their answers on whether it is easy to learn and use in the classroom are interesting. A percentage close to 40% indicates uncertainty in the relevant questions, as shown in Fig. 13.3.

Additionally, the intention to engage and implement robotic projects in the classroom is examined (Fig. 13.4). Teachers recognize that teaching and learning become effective (73.7%). In this case, about 40% seem hesitant about the application, and they do not consider it easy to use and state that they do not precisely understand how to interact with robotic activities. At the same time, it is thought that there will be difficulties in getting acquainted with this innovative tool. Consequently, 48.7% of

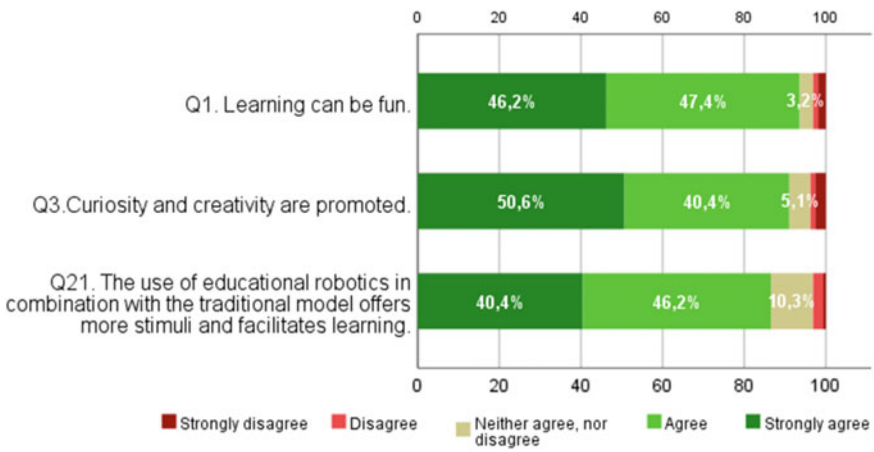



**Fig. 13.1** Educational robotics supports learning

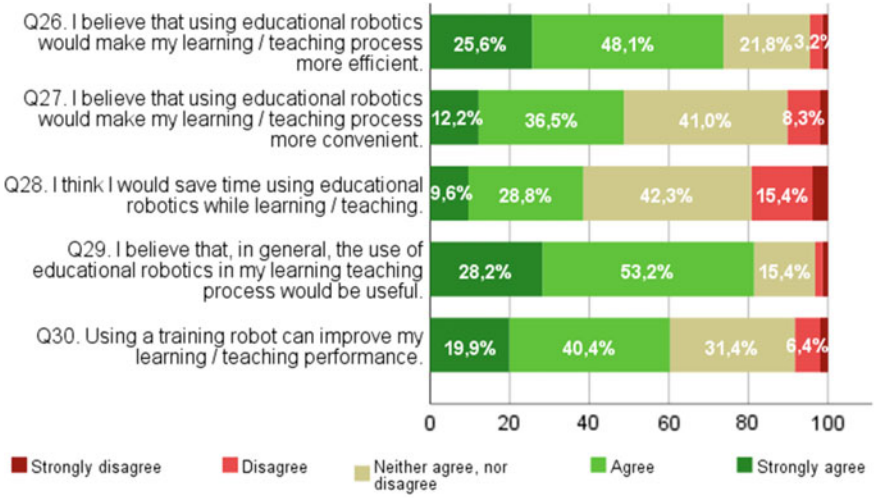



**Fig. 13.2** The effect of educational robotics on learning and teaching

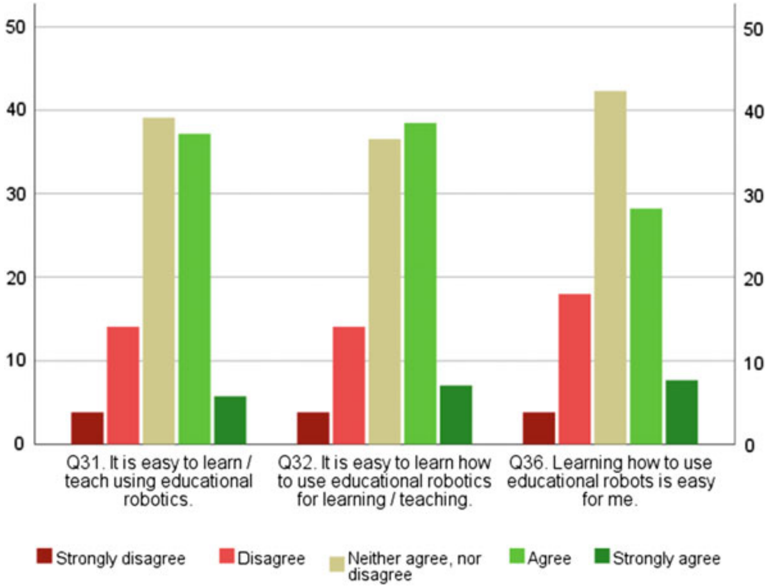



**Fig. 13.3** Ease of use of robotics

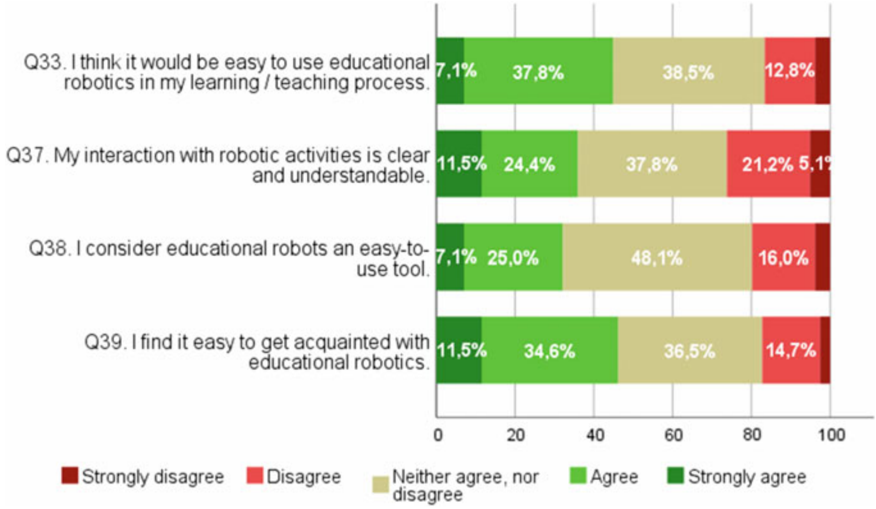



**Fig. 13.4** The intention to use educational robotics

the participants do not believe its use is convenient and are unsure about the proper teaching time management if they decide to use it.

Even more pronounced is the skepticism of teachers in their view that learning the operation of an educational robot requires a lot of effort (44.9%). Figures 13.5 and 13.6 show teachers' attitudes depending on the age group and teaching experience.

## 13.7.2 *Developing Skills Through Educational Robotics*

According to the literature, robotics is associated with developing various skills as students are actively involved in the learning process cognitively and emotionally (Papadakis et al., 2021). Some of the most commonly mentioned are technological skills (e.g., programming and coding), problem-solving and computational thinking (Atmatzidou & Dimitriadis, 2017), mathematical skills (e.g., measuring, pattern recognition (Estivill-Castro, 2020), language skills (e.g., reading, writing, vocalization) (Choi et al., 2019), social skills (e.g., collaboration) (Toh et al., 2016). We investigate these areas of skills as shown below (Fig. 13.7).

Moreover, while the contribution of robotics to courses such as science, math, technology seems to be recognized, the same is not valid for teaching skills such as reading and writing and teaching foreign languages. This reflects the lack of knowledge of the contribution of robotics beyond the STEM courses and highlights the need to find ways and opportunities to engage teachers with activities that will highlight the benefits of using it in fields other than science, technology, and technology, mathematics.

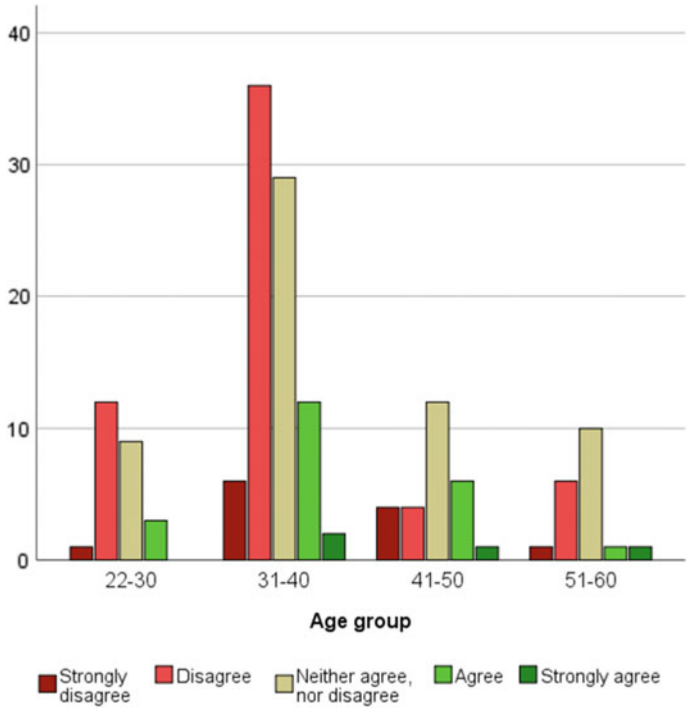



**Fig. 13.5** Learning how to operate an educational robot does not require much effort depending on age

### *13.7.3 Enhancing the Involvement of Teachers with Educational Robotics*

Participants are willing and interested in learning more about choosing educational robotics applications, how often they can apply them, what ages they are recommended, through relevant training, and if they have the necessary resources. Equally important is that they want to integrate educational robotics into the school lessons taught (Fig. 13.8).

Interesting is the correlation between the participants' age, teaching experience, education level, self-assessment of the level of knowledge in ICT with their answers to specific questions (Table 13.4). Younger teachers show greater receptivity to further training on various robotics applications and other related parameters, and the same is observed for teachers with less teaching experience. The level of education and the degree of self-assessment of their ICT knowledge for receptivity to their involvement in robotics seems to have a more significant impact. In general, a negative correlation was observed in 31 of the 42 questions (Table 13.4).

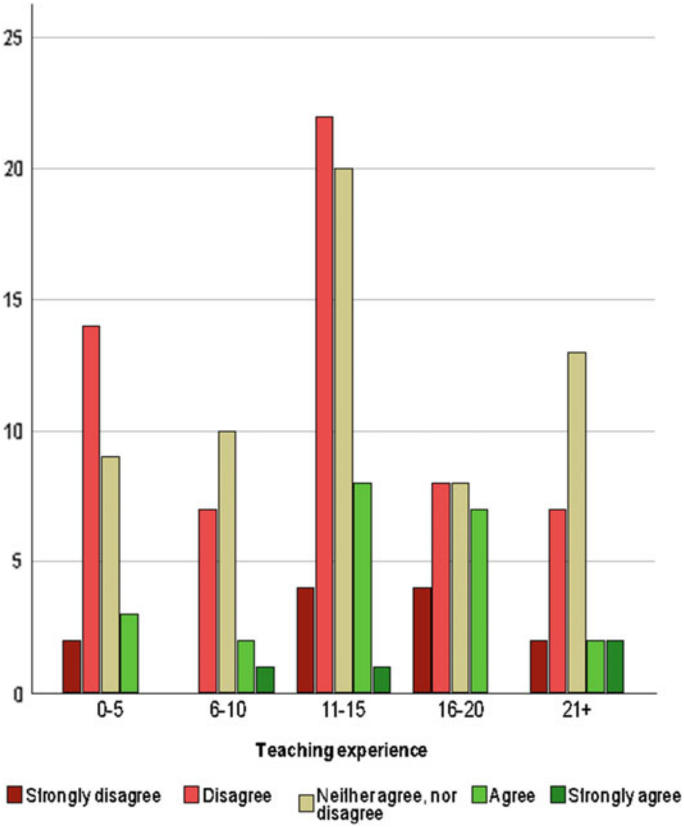



**Fig. 13.6** Learning how to operate an educational robot does not require much effort depending on teaching experience

## 13.8 Discussion—Conclusion

With the present study, we investigated the attitudes of primary school teachers towards the use of educational robotics. We explored through specific questions whether the attitudes of primary school teachers about robotics affect its use in the classroom. Teachers' attitudes are examined concerning learning, cognitive, personal, social skills, and training in this field. The need for research derives from the idea that integrating robotics into practice will increase depending on whether robotics is considered helpful for teaching, learning, and acquiring skills.

In general, teachers' attitudes on this issue have not been thoroughly researched (Karypi, 2018). Thus, the present study is added to the existing ones and strengthens the position that educational robotics offers many advantages in teaching and learning (Di Battista et al., 2020). Especially to young students where current experiences will shape future their cognitive, social, emotional development (Choi et al., 2019). Most

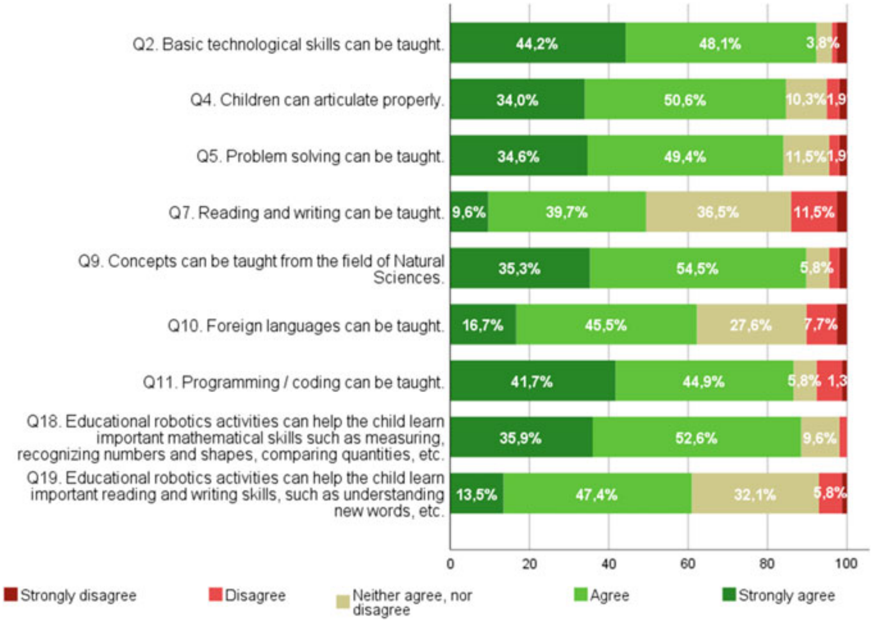



**Fig. 13.7** Contribution of robotics

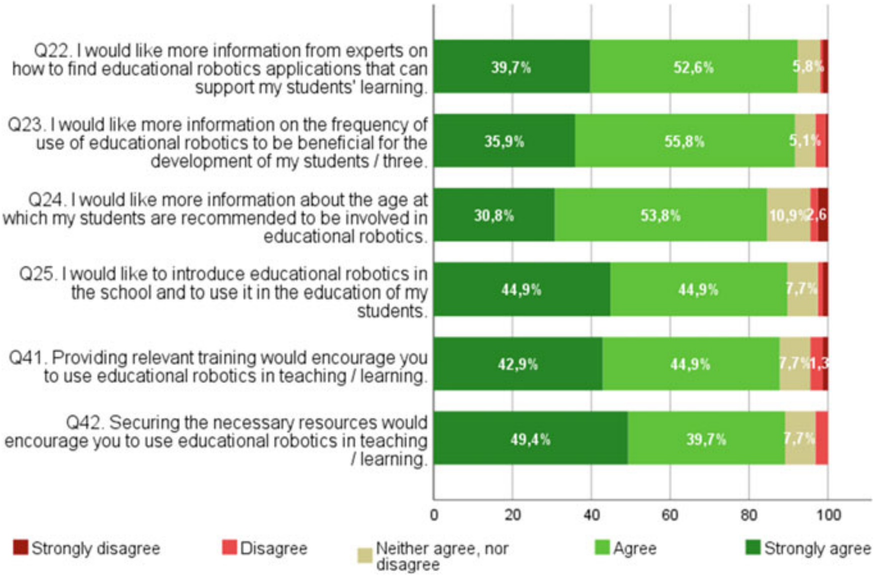



**Fig. 13.8** Perceptions of the participants to increase their interest in robotics

**Table 13.4** Participants' age group, teaching experience, education level, self-assessment of the level of knowledge in ICT, and their perceptions of robotics

| Correlations Spearman's rho | Age group | Teaching experience | Education level | Self-assessment of the level of knowledge in ICT |
|---|---|---|---|---|
| Age group | 1.000 | | | |
| Teaching experience | 0.850 | 1.000 | | |
| Education level | −0.130 | −0.114 | 1.000 | |
| Self-assessment of the level of knowledge in ICT | −0.047 | −0.018 | 0.283 | 1.000 |
| Q22. I would like more information from experts on finding educational robotics applications to support my students' learning | −0.243 | −0.214 | −0.031 | 0.095 |
| Q23. I would like more information on the frequency of use of educational robotics to be beneficial for the development of my students / three | −0.119 | −0.154 | −0.036 | 0.004 |
| Q24. I would like more information about the age at which my students are recommended to be involved in educational robotics | −0.128 | −0.168 | −0.047 | −0.074 |
| Q25. I would like to introduce educational robotics in the school and use it in my students' education | −0.049 | −0.105 | 0.167 | 0.168 |
| Q40. Learning how to operate an educational robot does not require much effort | 0.103 | 0.080 | 0.152 | 0.114 |

(continued)

**Table 13.4** (continued)

| Correlations Spearman's rho | Age group | Teaching experience | Education level | Self-assessment of the level of knowledge in ICT |
|---|---|---|---|---|
| Q42. Securing the necessary resources would encourage you to use educational robotics in teaching/learning | −0.080 | −0.060 | 0.105 | 0.181 |

teachers agree with this view, recognizing that students have stimuli in a fun way tailored to their needs. Through a creative combination of traditional tools and innovators such as robotics, they believe that the benefits increase as students' curiosity and creativity are further promoted.

Teachers in this study consider robotics to improve teaching and learning efficiency and learning but seem restrained in terms of ease of understanding and use it. To a large extent, they state ignorance of its use in the classroom. Even teachers with enough teaching experience (11–15 years) consider it takes much effort to get involved with robotics. Khanlari (2016), in his study, identified this very lack of familiarity of teachers with concepts and technologies of robotics. This strongly suggests the need to train in-service or pre-service teachers (Alimisis, 2019; Guven & Cakir, 2020; Papadakis et al., 2021; Piedade et al., 2020) to increase the chances that teachers will choose to teach through it.

Although participants associate robotics with technological skills (e.g., programming and coding), mathematics (e.g., problem-solving), language skills (e.g., expression, reading, writing, foreign language learning), and social skills, it is worth noting that they do not link robotics to language skills (Tzagkaraki et al., 2021). This attitude may be related to the perception that robotics is more associated with STEM courses (Estivill-Castro, 2020; Karypi, 2018; Kim et al., 2015; Theodoropoulos et al., 2016). Through deeper involvement with related activities, it will be realized that it is not limited only to these fields (Di Battista et al., 2020) but is a tool that can be flexibly used in various courses and projects. A revised version of the elementary school curriculum that will promote STEAM and robotics courses' integration will trigger teachers to link STEAM education to their experiences with robots. At the same time, relevant training with properly designed challenges will provide opportunities for inspiration and exploration of activities that can be implemented in the classroom (Estivill-Castro, 2020).

Compared to traditional learning models, learning outcomes and the learning process using robotics gain other value by developing a range of skills necessary for the twenty-first century, such as problem-solving, computational thinking, collaboration, critical thinking, and more. Furthermore, the degree of development of these skills may not be possible. Still, their cultivation is essential for the development of each child and not only for the school but especially for his life in general (Alimisis, 2019).

It is recognized that the value of robotic activities is excellent as with physical and specific materials students learn in actual conditions. So, if combined with existing textbooks and materials, the learning process can benefit all students (Alimisis, 2019).

The appropriate age to teach children robotics. Our research shows that primary school teachers do not have enough knowledge and find it difficult to understand information technology and robots. So significant is the percentage of participants who want to learn more about how they can enhance learning through robotics, how often they can implement related activities. Most importantly, most teachers seem to be encouraged to use robotics provided the necessary resources are secured (although there is little negative correlation with age group and teaching experience).

Teachers who act as guides and are called upon to keep up with the constant development of technology or new technologies are essential. In this context, teachers need to increase their ability to use technologies such as robotics in their classrooms (Guven & Cakir, 2020). It is necessary to change any negative attitudes with their training (Kim & Lee, 2016). Consider that pedagogical strategies using such technologies are appropriate for learning and teaching (Choi et al., 2019).

In conclusion, introducing educational robots in early and primary childhood classrooms will benefit teachers and students. The pedagogical strategy of using educational robotics has been cited in many studies as a powerful approach to teaching and learning, in CT skills development, in twenty-first century skills development (Kalogiannakis et al., 2021; Piedade et al., 2020).

However, to take full advantage of both possible and productive results, teachers must acquire basic knowledge about using technological resources to be comfortable and self-confident in their teaching performance (Choi et al., 2019). There were also shortages in the physical and technical equipment of the schools for the classes related to technology use, and this lack of equipment hinders the effective teaching of technology (Guven & Cakir, 2020).

The teache's role in the robotics context changes from a regulator to a mediator of the learning process. Learning improves as the teacher broaches the problems to be solved, provides the appropriate resources and the students, has an active role, tries ideas, collaborates, evaluates, and creates playfully (Alimisis, 2019). Modern society requires increasing opportunities to access cutting-edge technologies such as learning using robotics with democratic criteria for all students (Alimisis, 2013).

## 13.9 Limitations—Future Studies

The conclusions cannot be generalized to all teachers. The relevant findings apply to the survey sample population, with a certain probability, the acceptable limit of which is usually 99 or 95% (Error of measurement transition from sample to population). We are dealing with teachers; a similar study would be fascinating for end-users of the students. Research results such as the present could determine how perceptions of robotics relate to expanding their use in the classroom. Also, quality data collection could shed light on interesting aspects. In conclusion, the results can be used to design training workshops for teachers and the teachers themselves for reflection and self-improvement.

## Appendix 1

See Table 13.5.

## Appendix 2

### Factor analysis

Rotated Component Matrix[a].

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Q5 | 0.839 | | | | | | |
| Q3 | 0.839 | | | | | | |
| Q2 | 0.830 | | | | | | |
| Q1 | 0.824 | | | | | | |
| Q4 | 0.782 | | | | | | |
| Q9 | 0.777 | | | | | | |
| Q8 | 0.724 | | | | | | |
| Q6 | 0.715 | | | | | | |
| Q11 | 0.683 | | | | | | |
| Q18 | 0.534 | 0.431 | | | | | |
| Q29 | 0.509 | 0.422 | | | 0.407 | | |
| Q16 | | −0.826 | | | | | |
| Q17 | | −0.771 | | | | | |
| Q12 | | −0.758 | | | | | |
| Q14 | | −0.751 | | | | | |
| Q15 | | −0.732 | | | | | |
| Q42 | 0.423 | 0.539 | | 0.409 | | | |
| Q41 | | 0.520 | | 0.477 | | | |
| Q13 | | −0.484 | | | | | |
| Q21 | | 0.458 | | | | | |
| Q36 | | | 0.849 | | | | |
| Q38 | | | 0.807 | | | | |

(continued)

(continued)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Q39 | | | 0.792 | | | | |
| Q37 | | | 0.749 | | | | |
| Q40 | | | 0.740 | | | | |
| Q32 | | | 0.703 | | | | |
| Q33 | | | 0.657 | | 0.469 | | |
| Q31 | | | 0.596 | | 0.548 | | |
| Q23 | | | | 0.902 | | | |
| Q22 | | | | 0.892 | | | |
| Q24 | | | | 0.839 | | | |
| Q25 | | | | 0.599 | | | |
| Q28 | | | | | 0.792 | | |
| Q27 | | | | | 0.729 | | |
| Q30 | | | | | 0.607 | | |
| Q26 | | | | | 0.483 | | |
| Q7 | 0.456 | | | | | 0.712 | |
| Q19 | | | | | | 0.710 | |
| Q10 | 0.465 | | | | | 0.682 | |
| Q20 | | 0.403 | | | 0.405 | 0.443 | |
| Q35 | | | | | | | 0.792 |
| Q34 | | | | | | | 00.676 |
| Extraction method: principal component analysis | | | | | | | |
| Rotation method: varimax with Kaiser normalization | | | | | | | |
| a. Rotation converged in 8 iterations | | | | | | | |

| KMO and Bartlett's test | | |
|---|---|---|
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.884 | |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 5313.265 |
| | df | 861 |
| | Sig | 0.000 |

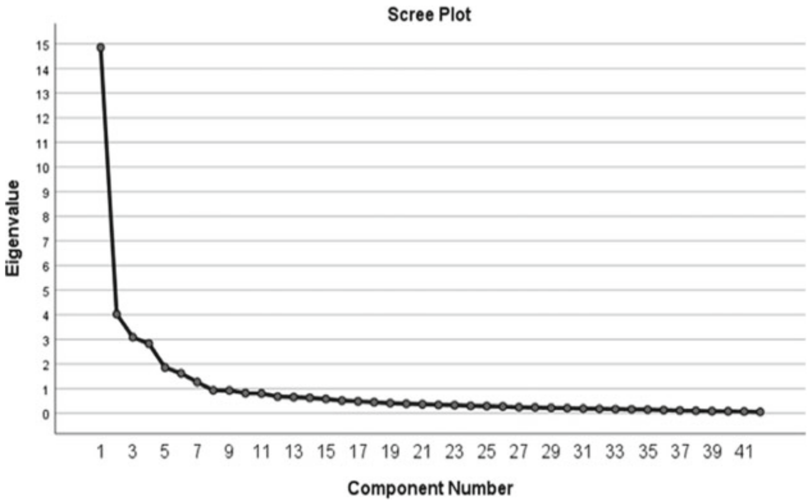
**Table 13.5** Mean values, standard deviations, skewness, and kurtosis

| | N | M | SD | Skewness | Std. Error | Kurtosis | Std. Error |
|---|---|---|---|---|---|---|---|
| Q1 | 156 | 4.35 | 0.776 | −1.866 | 0.194 | 5.590 | 0.386 |
| Q2 | 156 | 4.30 | 0.822 | −1.880 | 0.194 | 5.230 | 0.386 |
| Q3 | 156 | 4.35 | 0.849 | −1.903 | 0.194 | 4.808 | 0.386 |
| Q4 | 156 | 4.12 | 0.857 | −1.283 | 0.194 | 2.403 | 0.386 |
| Q5 | 156 | 4.12 | 0.853 | −1.249 | 0.194 | 2.354 | 0.386 |
| Q6 | 156 | 4.09 | 0.845 | −1.081 | 0.194 | 1.651 | 0.386 |
| Q7 | 156 | 3.42 | 0.909 | −.369 | 0.194 | 0.017 | 0.386 |
| Q8 | 156 | 3.97 | 0.842 | −1.331 | 0.194 | 2.879 | 0.386 |
| Q9 | 156 | 4.19 | 0.810 | −1.535 | 0.194 | 3.846 | 0.386 |
| Q10 | 156 | 3.66 | 0.933 | −0.621 | 0.194 | 0.340 | 0.386 |
| Q11 | 156 | 4.19 | 0.902 | −1.351 | 0.194 | 1.842 | 0.386 |
| Q12 | 156 | 1.72 | 0.816 | 1.126 | 0.194 | 1.336 | 0.386 |
| Q13 | 156 | 2.26 | 1.023 | 0.661 | 0.194 | 0.046 | 0.386 |
| Q14 | 156 | 2.22 | 0.911 | 0.279 | 0.194 | −0.498 | 0.386 |
| Q15 | 156 | 1.76 | 0.746 | 1.078 | 0.194 | 2.106 | 0.386 |
| Q16 | 156 | 1.96 | 0.894 | 0.900 | 0.194 | 0.791 | 0.386 |
| Q17 | 156 | 2.03 | 0.980 | 0.852 | 0.194 | 0.173 | 0.386 |
| Q18 | 156 | 4.22 | 0.696 | −0.684 | 0.194 | 0.582 | 0.386 |
| Q19 | 156 | 3.66 | 0.831 | −0.454 | 0.194 | 0.413 | 0.386 |
| Q20 | 156 | 3.65 | 0.886 | −0.259 | 0.194 | −0.346 | 0.386 |
| Q21 | 156 | 4.23 | 0.786 | −1.080 | 0.194 | 1.639 | 0.386 |
| Q22 | 156 | 4.29 | 0.719 | −1.445 | 0.194 | 4.555 | 0.386 |
| Q23 | 156 | 4.24 | 0.719 | −1.231 | 0.194 | 3.149 | 0.386 |
| Q24 | 156 | 4.08 | 0.850 | −1.375 | 0.194 | 3.056 | 0.386 |
| Q25 | 156 | 4.31 | 0.776 | −1.437 | 0.194 | 3.390 | 0.386 |
| Q26 | 156 | 3.94 | 0.848 | −.714 | 0.194 | 0.789 | 0.386 |
| Q27 | 156 | 3.49 | 0.883 | −0.217 | 0.194 | 0.084 | 0.386 |
| Q28 | 156 | 3.25 | 0.961 | −0.124 | 0.194 | −0.173 | 0.386 |
| Q29 | 156 | 4.05 | 0.793 | −0.955 | 0.194 | 10.871 | 0.386 |
| Q30 | 156 | 3.70 | 0.926 | −0.450 | 0.194 | 0.077 | 0.386 |
| Q31 | 156 | 3.27 | 0.911 | −0.406 | 0.194 | −0.006 | 0.386 |
| Q32 | 156 | 3.31 | 0.934 | −0.412 | 0.194 | −0.072 | 0.386 |
| Q33 | 156 | 3.31 | 0.921 | −0.416 | 0.194 | 0.050 | 0.386 |
| Q34 | 156 | 1.93 | 0.881 | 0.655 | 0.194 | −0.063 | 0.386 |
| Q35 | 156 | 2.41 | 1.228 | 0.612 | 0.194 | −0.656 | 0.386 |
| Q36 | 156 | 3.18 | 0.947 | −0.090 | 0.194 | −0.211 | 0.386 |

(continued)

**Table 13.5** (continued)

| | N | M | SD | Skewness | Std. Error | Kurtosis | Std. Error |
|---|---|---|---|---|---|---|---|
| Q37 | 156 | 3.16 | 1.050 | 0.012 | 0.194 | −0.529 | 0.386 |
| Q38 | 156 | 3.15 | 0.910 | −0.050 | 0.194 | 0.085 | 0.386 |
| Q39 | 156 | 3.38 | 0.959 | −0.202 | 0.194 | −0.331 | 0.386 |
| Q40 | 156 | 2.67 | 0.904 | 0.287 | 0.194 | −0.118 | 0.386 |
| Q41 | 156 | 4.25 | 0.832 | −1.384 | 0.194 | 2.573 | 0.386 |
| Q42 | 156 | 4.35 | 0.760 | −1.139 | 0.194 | 1.111 | 0.386 |




# Appendix 3

| Construct | Item | Source |
|---|---|---|

(continued)

(continued)

| Construct | Item | Source |
|---|---|---|
| Contribution (skills) | Q1. Learning can be fun<br>Q2. Basic technological skills can be taught<br>Q3. Curiosity and creativity are promoted<br>Q4. Children can articulate adequately<br>Q5. Problem-solving can be taught<br>Q6. Allows children to relax<br>Q7. Reading and writing can be taught<br>Q8. Mathematical concepts can be taught<br>Q9. Concepts can be taught from the field of Natural Sciences<br>Q10. Foreign languages can be taught<br>Q11. Programming/coding can be taught<br>Q18. Educational robotics activities can help the child learn essential math skills such as measuring, recognizing numbers and shapes, comparing quantities, etc.<br>Q19. Educational robotics activities can help the child learn essential reading and writing skills, such as understanding new words<br>Q20. When a child learns math, reading, and writing, educational robotics applications are as crucial as other learning resources (such as reading books)<br>Q21. The use of educational robotics in combination with the traditional model offers more stimuli and facilitates learning | (Kandlhofer & Steinbauer, 2015) |

(continued)

(continued)

| Construct | Item | Source |
|---|---|---|
| Attitude Toward Using (Student's development) | Q12. The use of educational robotics is harmful to children's development<br>Q13. Children do not need to know how to use robotic applications for their education<br>Q14. Traditional educational material is better than educational robotics application material<br>Q15. Educational robotics does not support children's learning<br>Q16. The use of educational robotics distracts children from other experiences that are important for their development<br>Q17. The use of educational robotics leads the child to less social contact with other children | (Weng et al., 2018) |
| Receptivity to training -professional development | Q22. I would like more information from experts on finding educational robotics applications to support my students' learning<br>Q23. I would like more information on the frequency of use of educational robotics to be beneficial for the development of my students / three<br>Q24. I would like more information about the age at which my students are recommended to be involved in educational robotics<br>Q25. I would like to introduce educational robotics in the school and use it in my students' education<br>Q41. Providing relevant training would encourage you to use educational robotics in teaching/learning<br>Q42. Securing the necessary resources would encourage you to use educational robotics in teaching/learning | Rhodes and Beneicke (2003) |

(continued)

(continued)

| Construct | Item | Source |
|---|---|---|
| Intention to use | Q26. I believe that using educational robotics would make my learning/teaching process more efficient<br>Q27. I believe that using educational robotics would make my learning/teaching process more convenient<br>Q28. I think I would save time using educational robotics while learning/teaching<br>Q29. I believe that, in general, the use of educational robotics in my learning teaching process would be helpful<br>Q30. Using an educational robot can improve my learning/teaching performance | (Burton-Jones & Hubona, 2005)<br>(Davis, 1989) |
| Ease of access | Q31. It is easy to learn/teach using educational robotics<br>Q32. It is easy to learn how to use educational robotics for learning/teaching<br>Q33. I think it would be easy to use educational robotics in my learning/teaching process<br>Q34. I think using educational robots will be a waste of my time<br>Q35. I think the use of educational robots is an inefficient way of learning/teaching<br>Q36. Learning how to use educational robots is easy for me<br>Q37. My interaction with robotic activities is clear and understandable<br>Q38. I consider educational robots an easy-to-use tool<br>Q39. I find it easy to get acquainted with educational robotics<br>Q40. Learning how to operate an educational robot does not require much effort | (Burton-Jones & Hubona, 2005)<br>(Davis, 1989)<br>(Ninomiya et al., 2015)<br>(Venkatesh & Davis, 2000) |

## References

Ackermann, E. (2001). Piaget's constructivism, Papert's constructionism: What's the difference. *Future of Learning Group Publication, 5*(3), 438.

Alimisis, D. (2013). Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education, 6*(1), 63–71. Retrieved March 22, 2021, from https://www.learntechlib.org/p/148617/

Alimisis, D. (2019). Teacher training in educational robotics: The ROBOESL project paradigm. *Tech Know Learn, 24*, 279–290. https://doi.org/10.1007/s10758-018-9357-0

Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research (J-PEER), 9*(2). https://doi.org/10.7771/2157-9288.1223

Atmatzidou, S., & Demetriadis, S. (2017). A didactical model for educational robotics activities: A study on improving skills through strong or minimal guidance. In D. Alimisis, M. Moro & E. Menegatti (Eds.), *Educational Robotics in the Makers Era. Edurobotics 2016. Advances in Intelligent Systems and Computing* (Vol. 560, pp. 58–72). Gewerbestr, Switzerland: Springer Nature. https://doi.org/10.1007/978-3-319-55553-9_5

Burton-Jones, A., & Hubona, G. S. (2005). Individual differences and usage behavior: Revisiting a technology acceptance model assumption. *Database for Advances in Information Systems, 36*(2), 58–77.

Bergman, M. (1998). A theoretical note on the differences between attitudes, opinions, and values. *Swiss Political Science Review, 4*, 81–93.

Camilleri, P. (2017). Minding the gap. Proposing a teacher learning-training framework for the integration of robotics in primary schools. *Informatics Education, 16*, 165–179.

Chalmers, C. (2017). Preparing Teachers to Teach STEM through Robotics. *International Journal of Innovation in Science and Mathematics Education, 25.*

Chiazzese, G., Arrigo, M., Chifari, A., Lonati, V., & Tosto, C. (2019). Educational robotics in primary school: Measuring the development of computational thinking skills with the Bebras Tasks. *Informatics, 6*(4), 43. https://doi.org/10.3390/informatics6040043

Choi, W., Stantic, B., & Jo, J. (2019). Educators' perception on the use of robots in the early childhood environment. *International Journal of Advanced Smart Convergence, 8*(3), 138–144. https://doi.org/10.7236/IJASC.2019.8.3.138

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). Routledge/Taylor & Francis Group.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

Di Battista, S., Pivetti, M., Moro, M., & Menegatti, E. (2020). Teachers' opinions towards educational robotics for special needs students: An exploratory Italian study. *Robotics, 9*(3), 72. https://doi.org/10.3390/robotics9030072

Estivill-Castro, V. (2020). Inviting teachers to use educational robotics to foster mathematical problem-solving. In M. Merdan, W. Lepuschitz, G. Koppensteiner, R. Balogh, & D. Obdržálek (Eds.), *Robotics in Education* (Vol. 1023). RiE 2019. Advances in intelligent systems and computing. Springer. https://doi.org/10.1007/978-3-030-26945-6_22

Faisal, A., Kapila, V., & Iskander, M. G. (2012). *Using Robotics to Promote Learning in Elementary Grades.* Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. https://doi.org/10.18260/1-2--22196

Feurzeig, W., Papert, S., Bloom, M., Grant, R., & Solomon, C. (1970). Programming-languages as a conceptual framework for teaching mathematics. *SIGCUE Outlook*, *4*(2), 13–17. https://doi.org/10.1145/965754.965757

George, D., & Mallery, P. (2003). *Using SPSS for windows step by step: A simple guide and reference* (4th ed.). Pearson Education.

Guven, G., & Cakir, N. K. (2020). investigation of the opinions of teachers who received in-service training for Arduino-assisted robotic coding applications. *Educational Policy Analysis and Strategic Research, 15*(1), 253–274. https://doi.org/10.29329/epasr.2020.236.14

Kalogiannakis, M., Tzagkaraki, E., & Papadakis, St. (2021). A systematic review of the use of BBC Micro: Bit in primary school. In *Proceedings of the 10th Virtual Edition of the International Conference New Perspectives in Science Education* (pp. 379–384), Italy-Florence: Filodiritto-Pixel, 18–19 March 2021. https://doi.org/10.26352/F318_2384-9509

Kandlhofer, M., & Steinbauer, G. (2015). Evaluating the impact of educational robotics on pupils' technical- and social-skills and science-related attitudes. *Robotics and Autonomous Systems, 75B*, 679–685. https://doi.org/10.1016/j.robot.2015.09.007

Karypi, S. (2018). Educational robotics application in primary and secondary education: A challenge for the Greek teachers society. *Journal of Contemporary Education, Theory & Education Research, 2*(1), 9–14.

Khanlari, A., & Kiaie, F. M. (2015) Using robotics for STEM education in primary/elementary schools: Teachers' perceptions. In *10th International Conference on Computer Science & Education* (ICCSE 2015), Fitzwilliam College, Cambridge University, UK.

Khanlari, A. (2016). Teachers' perceptions of the benefits and the challenges of integrating educational robots into primary/elementary curricula. *European Journal of Engineering Education, 41*(3), 320–330. https://doi.org/10.1080/03043797.2015.1056106

Kim, S., & Lee, Y. (2016). The effect of robot programming education on attitudes towards robots. *Indian journal of science and technology, 9*.

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education, 91*, 14–31. https://doi.org/10.1016/j.compedu.2015.08.005

Kyriazopoulos, I., Koutromanos, G., Voudouri, A., & Galani, A. (2021). Educational robotics in primary education: A systematic literature review. In St. Papadakis & M. Kalogiannakis (Eds.), *Handbook of research on using education robotics to facilitate student learning* (pp. 377–401). IGI Global. https://doi.org/10.4018/978-1-7998-6717-3.ch015

Negrini, L. (2020). Teachers' attitudes towards educational robotics in compulsory school. *Italian Journal of Educational Technology, 28*(1), 77–90. https://doi.org/10.17471/2499-4324/1136

Ninomiya, T., Fujita, A., Suzuki, D., & Umemuro, H. (2015). *Development of the multi-dimensional robot attitude scale: Constructs of people's attitudes towards domestic robots* (pp. 482–491). Springer.

Nomura, T., Kanda, T., Suzuki, T., & Kato, K. (2008). Prediction of human behavior in human-robot interaction using psychological scales for anxiety and negative attitudes toward robots. *IEEE Transactions on Robotics, 24*(2), 442–451. https://doi.org/10.1109/TRO.2007.914004

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307–332. https://doi.org/10.3102/00346543062003307

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences, 11*, 204. https://doi.org/10.3390/educsci11050204

Pickens, J. (2005). Attitudes and Perceptions. *Organizational behavior in health care* (pp. 43–75). Jones and Bartlett Publishers.

Piedade, J., Dorotea, N., Pedro, A., & Matos, J. F. (2020). On teaching programming fundamentals and computational thinking with educational robotics: A didactic experience with pre-service teachers. *Education Sciences, 10*(9), 214. https://doi.org/10.3390/educsci10090214

Reich-Stiebert N., Eyssel F. (2016). Robots in the classroom: What teachers think about teaching and learning with education robots. In: A. Agah, J. J. Cabibihan, A. Howard, M. Salichs & H. He (Eds.), *Social Robotics* (Vol. 9979). ICSR 2016, Lecture Notes in Computer Science. Springer. https://doi.org/10.1007/978-3-319-47437-3

Rhodes, C., & Beneicke, S. (2003). Professional development support for poorly performing teachers: Challenges and opportunities for school managers in addressing teacher learning needs. *Journal of In-service Education, 29*, 123–140.

Robson, C. (2002). *Real world research: A resource for social scientists and practitioner-researchers*. Blackwell Publishers.
Sapounidis, T., & Alimisis, D. (2020). Educational robotics for STEM: A review of technologies and some educational considerations. In *Science and mathematics education for 21st century citizens: Challenges and ways forward* (pp. 167–190). Nova Science Publishers.
Scaradozzi, D., Sorbi, L., Pedale, A., Valzano, M., & Vergine, C. (2015). Teaching robotics at the primary school: An innovative approach. *Procedia - Social and Behavioral Sciences, 174*, 3838–3846.
Theodoropoulos, A., Antoniou, A., & Lepouras, G. (2016). Educational robotics in the service of CSE: A study based on the PanHellenic competition. In *Proceedings of the 11th Workshop in Primary and Secondary Computing Education*. ACM.
Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Educational Technology & Society, 19*(2), 148–163.
Tzagkaraki, E., Papadakis, St., & Kalogiannakis, M. (2021). Esxploring the use of educational robotics in primary school and its possible place in the curricula. In M. Malvezzi, D. Alimisis & M. Moro (Eds.), *Education in & with robotics to foster 21st century skills*. Proceedings of EDUROBOTICS 2020, Online Conference February 25–26, 216–229. Springer, https://doi.org/10.1007/978-3-030-77022-8_19
Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 45*(2), 186–204.
Vlasopoulou, M., Kalogiannakis, M., & Sifaki, E. (2021). Investigating teachers' attitude and behavioral intentions for the impending integration of STEM education in primary school. In St. Papadakis & M. Kalogiannakis (Eds.), *Handbook of research on using education robotics to facilitate student learning* (pp. 235–256). IGI Global. https://doi.org/10.4018/978-1-7998-6717-3.ch009
Weng, F., Yang, R.-J., Ho, H.-J., & Su, H.-M. (2018). A TAM-based study of the attitude towards use intention of multimedia among school teachers. *Applied System Innovation, 1*(3), 36. https://doi.org/10.3390/asi1030036

# Chapter 14
# Aerial Robots: To Use or not to Use Them in Teaching and Learning?

**Tryfon Sivenas and George Koutromanos**

**Abstract** The aim of this study was to examine pre-service and in-service teachers' perceptions regarding the use of drones in teaching. The study sample consisted of 80 pre-service and 101 in-service teachers. After a brief introduction to drone technology, the participants completed tasks that required assembling, programming, virtually simulating and flying 16 multirotor drones. Data were collected via an online questionnaire using variables and questions adapted from the Theory of Planned Behavior. The results indicated that pre-service and in-service teachers showed positive attitudes, intention and behavioral beliefs towards using drones in teaching. A positive correlation between attitudes and intention was found. Results also indicated that a number of pupil skills and subjects will be enhanced by using drones in the classroom. Finally, pre-service teachers had stronger intentions and more positive attitudes, behavioral beliefs and perceptions compared to in-service teachers. This study has a number of implications regarding the use of drones in teaching as well as the need to develop teacher training programs in order to successfully integrate drone technology into future classrooms.

**Keywords** Educational aerial robotics · Drones · Pre-service and in-service teachers · Attitudes · Beliefs · Perceptions

## 14.1 Introduction

In recent years, the Internet and technological evolution have resulted in the development of next generation mobile robotics with applications in various sectors (Bogue, 2020), divided into underwater, ground and aerial robotics (Fulton et al., 2019; Rubio et al., 2019). In the field of education, ground robotics were introduced by Papert

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(1993) in the early 1980s, who offered his own perspective on the theory of constructivism, through the theory of constructionism. According to the theory of constructionism, manipulating an artifact is essential for the construction of knowledge and turns students from passive receivers to active participants during the learning process (Papert, 1993). The theory of constructionism can be applied in educational robotics since many robots require design, control, assembly and programming concepts (Alimisis, 2013; Staszowski & Bers, 2005).

Nowadays, various ground robots have been developed (e.g., NAO, Pepper, Bee-Bot, Mindstorms), the use of which in education has shown positive effects on learning (Ahmad et al., 2020), such as increased knowledge (Khanlari, 2015), motivation (Arís & Orcos, 2019) and engagement among pupils (Kim et al., 2015) as well as the development of various skills (Toh et al., 2016). Contrary to ground robotics, underwater robotics in the field of education began around the end of the first decade of the 2000s. Despite its limited extent, underwater robotics has shown a positive effect, with participants mentioning motivation, higher levels of interest, creativity and active engagement (Scaradozzi et al., 2019; Stolkin et al., 2007).

The implementation of aerial robotics in education began in the early 2010s. Aerial robotics is a field which combines several disciplines (e.g., Mechanical and Electrical Engineering, Biomedical Engineering, Computer Science) and explores the design, construction, and operation of aerial robots (Feron & Johnson, 2008; Lupashin et al., 2014; Santoso et al., 2021). An aerial robot is defined as any robot that is capable of flight. Aerial robots can either fly under the remote control of a human or -after programming and configuration- offer various levels of autonomy which allow them to fly without human intervention (Sampedro et al., 2018; Zarafshan et al., 2010). A category of aerial robots is drones (Liew & Yairi, 2013; Nonami et al., 2019). A drone is defined as an unmanned aerial vehicle which can be remotely operated by a user or fly on its own using its embedded systems (Arnold et al., 2018; Mahony et al., 2016; Zeng et al., 2019). Drones have certain affordances that are not found in other robots, such as the ability to fly, interact and perform tasks in the three-dimensional environment; the secure collection of aerial data; the ability to take pictures and record videos through bird's-eye view, provided by their camera (Tezza et al., 2020); and the ability of autonomous flight (Karydis & Kumar, 2017; Rubio et al., 2019). Recently, a category of drones has emerged specifically designed for educational purposes, such as Ryze Tello EDU, Makeblock Airblock for STEAM education, Parrot Mambo EDU, and Bitcraze Crazyflie. Drones for education have a number of additional affordances, such as flight programming through visual block-based programming environments (e.g., Scratch, Blockly, Dronely), flight simulation for drone operation training (e.g., DJI virtual flight, Drone flight simulator), as well as a number of mobile apps with educational activities for students (e.g., DroneBlocks, Makeblock, Tynker, Tello EDU). All of the above have contributed to the advancement of research on drone use in every level of education. However, the use of drones by teachers remains limited.

To date, the majority of literature in the field of education mainly focuses on the use of drones by students. A number of researchers noted that students, following their interaction with drones, showed enhanced interest and engagement (Carnahan et al., 2016), critical and innovative thinking (Cliffe, 2019), decision making (Abarca et al., 2017), computational thinking (Bermúdez et al., 2019), increased motivation (Chen et al., 2019), understanding of aviation regulation (Chou, 2018), cross-domain learning as well as positive attitudes towards problem-solving and hands-on capabilities (Niedzielski, 2018). In general, it appears that drones create "an enjoyable learning environment" (Carnahan et al., 2016), enable pupils to explore the world through "bird's-eye view" via use of the camera (Ng & Cheng, 2019) and constitute "one of the most innovative educational tools" (Niedzielski, 2018). In view of this, drones can play a facilitating role, as they help pre-service and in-service teachers to become familiar with and confident in educational robotics (Cañas et al., 2020).

Consequently, even though drones have been used in education for almost a decade, there are few studies that investigate the perceptions of pre-service and in-service teachers in using drones in teaching. To the best of our knowledge, no study investigates the factors which affect the use of drones in teaching according to pre-service and in-service teachers. According to Teo (2011), the teacher is one of the key players in any effective uptake of Information and Communication Technologies (ICT) in schools. Several empirical and literature review studies (e.g., Scherer & Teo, 2019; Scherer et al., 2019; Teo & Lee, 2010) which make use of the framework of many technology acceptance models and theories (e.g., Technology Acceptance Model, Theory of Planned Behavior) have indicated that the attitudes, beliefs and perceptions of pre-service and in-service teachers regarding technology constitute major psychological factors that impact the implementation and continuation of digital technologies in teaching. As stated by Reich-Stiebert and Eyssel (2016), it is important to investigate potential end users' (i.e., teachers') attitudes before digital technologies are introduced into practice and, especially, to investigate their expectations, concerns and obstacles in order to enhance their acceptance. By exploring the perceptions of pre-service and in-service teachers regarding the use of drones in teaching, one can identify the factors that could encourage or discourage technology acceptance and, therefore, drone use in the classroom.

The aim of the present study was to explore pre-service and in-service teachers' attitudes, beliefs, perceptions and intentions regarding the use of drones in their future classrooms. Making use of the theoretical background of the Theory of Planned Behavior (TPB) (Ajzen, 1991), this study addresses the following research questions:

1. What is the intention and attitude of pre-service and in-service teachers regarding the use of drones in their future teaching?
2. What are the behavioral beliefs of pre-service and in-service teachers regarding the advantages and disadvantages of using drones in teaching and learning, as well as the control beliefs regarding the factors that facilitate this use?
3. Is there a statistically significant correlation between pre-service and in-service teachers' intention and behavioral and control beliefs regarding the use of drones in teaching and learning?
4. What are pre-service and in-service teachers' perceptions regarding the skills that can be developed through the use of drones in teaching and learning?

5. In which subjects do pre-service and in-service teachers believe that drones can be used?
6. Are there any statistically significant differences between pre-service and in-service teachers regarding their intentions, attitudes and behavioral and control beliefs about the use of drones in teaching and learning, their perceptions regarding the skills that can be developed through the use of drones, and the subjects in which drones can be used?

This study contributes to the field of aerial robotics in education and, using variables adapted from TPB, fills the gap by exploring and revealing pre-service and in-service teachers' intentions, attitudes, perceptions, and behavioral and control beliefs relating to the use of drones in teaching. After investigating current research in the field of ground educational robotics, this study is the first to investigate the perceptions of pre-service and in-service teachers on aerial robotics. These will assist further research on the design of a drone training framework for in-service teachers, on the one hand, and a teaching framework within current pre-service teachers' study programs in university education departments, on the other hand. It will also assist the ever-growing research on educational drones.

The structure of this chapter is as follows: Sect. 14.2 describes the terms, characteristics, types and categories of drones. Section 14.3 presents the theoretical framework of this study as well as relevant studies regarding pre-service and in-service teachers' attitudes and perceptions towards educational robotics. Next, Sect. 14.4 presents the study's methodology, while Sect. 14.5 presents the results. Lastly, Sect. 14.6 discusses the results and presents the main conclusions as well as the limitations of the study and directions for future research.

## 14.2 Characteristics of Drones

Opinions differ regarding the origin of the term "drone". According to some sources, it originated from the male honey bee, the drone (Custers, 2016; Perrelet, 1970). According to other sources, the term is an acronym, i.e., "Dynamic Remotely Operated Navigation Equipment" (D.R.O.N.E.) (Nurdin et al., 2019). Some of the most commonly used terms in research literature include "Remotely Piloted Aircraft System" (RPAS), "Unmanned Aerial Vehicle" (UAV), as well as "Unmanned Aircraft System" (UAS) (FAA, 2021; Vergouw et al., 2016). The term that tends to prevail is "Unmanned Aircraft System" (UAS), proposed by the US Federal Aviation Administration (FAA). The definition of a UAS is "an aircraft that is operated without direct human intervention from within or on the aircraft" (FAA, 2021). Aside from these terminologies, the drone is referred to in related literature as "flying robot" (Tomić & Haddadin, 2019), "aerial robot" (Park et al., 2016), "airborne robot" (Kim, 2013), "robotic aircraft" (Abutalipov et al., 2016), "micro aerial vehicle" (Kumar & Michael, 2012), "quadcopter" (Allison et al., 2020), and "quadrotor" (Rojas Viloria et al., 2020).

The large number of terms is due to the drone's interdisciplinary nature, the evolution of its terminology, and the perspective from which each study chooses to approach it. According to certain disciplines, a drone is not defined only as the robotic flying vehicle, but also as the entire infrastructure system that supports the communication of the robotic flying vehicle with the control station/controller/operator (Feron & Johnson, 2008; Nex & Remondino, 2014). So, studies that focus on the technology embedded in drones tend to use terms that simply describe the drone as a robotic flying vehicle/flying platform, while studies that focus on drone infrastructure tend to use different terminology in an attempt to include the entire range of its abilities (Custers, 2016). For example, studies that focus on engineering often refer to drones as multicopters/multirotors or quadcopters/quadrotors (e.g., Allison et al., 2020; Gaponov & Razinkova, 2012), studies that focus on aerospace technologies refer to drones as UAVs, aerial robots or flying robots (e.g., Boon et al., 2016; Nurdin et al., 2020), studies that focus on robotics refer to drones as micro aerial vehicles or quadcopters (e.g., Cliffe, 2019; Kumar & Michael, 2012), studies that focus on geomatics refer to drones as RPAS or UAS (e.g., Tomić & Haddadin, 2019), while there are studies that refer to aerial robots by their commercial name, i.e., drones (e.g., Nex & Remondino, 2014).

On the other hand, several researchers claim that the large number of terms has emerged due to attempts by the research community to stop the propagation and use of the term "drone" and replace it with new terms, since they believe it triggers negative visions and perceptions to the public due to its association with warfare (Aydin, 2019; Custers, 2016; PytlikZillig et al., 2018). So, even though certain terms (UAV, UAS, RPAS) have been established to better describe drones, they have been adopted only by air traffic organizations and, partially, by the research community, while the public as well as manufacturers (DJI, 2021; Parrot, 2021) still refer to them as drones.

In educational research literature, there are two types of drones being used, i.e., multirotor or multicopter drones and fixed-wing drones (Niedzielski, 2018). Drones that are described as multicopters or multirotors are propelled by a number of rotors ($\geq 2$) (Boon et al., 2017). A type of drone that belongs to this category is the quadrotor or quadcopter type, which has four rotors (Vergouw et al., 2016). Drones of this type do not require a large amount of space for takeoff, since they launch vertically and are durable and easy to use (Allison et al., 2020). As for the flight area, multirotor drones can be used within the interior space of a classroom or a gym as well as in any exterior space. On the other hand, fixed-wing drones rely on their wings to fly (Boon et al., 2017). They have features that are similar to airplanes, require a fair amount of space for their takeoff, are not as flexible to use as their multirotor counterparts, but are capable of traveling a large distance. Due to increased space requirements, they can be deemed appropriate for use in exterior spaces, such as a school yard or an outdoor area built especially for takeoff.

Another characteristic of drones relates to flight autonomy, i.e., the time during which the drone can remain airborne before its battery runs out. Even though the average flight autonomy of a drone for education depends on various factors (e.g., drone size, use of camera, maneuvers, speed, weather conditions, use in an interior or an exterior space), it is at any rate considered relatively small due to the limited capacity of its battery (Chou, 2018). For example, a drone for education can have an average flight time of 8–10 min (e.g., Ryze Tello EDU). This type of limitation will become increasingly scarce in the future as the capacity of the battery is expected to increase (which will in turn lead to an increase of the average flight time), as research focuses on new lightweight high-capacity batteries (Selim & Kamal, 2018), charging stations (Jawad et al., 2019) and new charging systems for drones (Wu et al., 2020).

One of the affordances of drones is a camera for taking pictures and recording videos through bird's-eye view. Another affordance is the ability to program the drone in order to perform an autonomous flight. The autonomous flight is performed after the drone's programming and configuration. The user can write a code in several programming languages (e.g., Scratch, Python, Swift, Java, C++, Assembly) or design a flight plan using an autopilot (e.g., Pixhawk autopilot, ArduPilot) in order for the drone to perform an autonomous flight. During the execution of the program, the drone performs the flight with no additional intervention by the user. Another affordance is real-time data collection (Vergouw et al., 2016).

The latter is accomplished through the built-in real-time data collecting sensors (e.g., of altitude, speed, distance, temperature) in addition to other sensors which allow drones to navigate autonomously in an area. Also, additional sensors can be attached which enable the measurement of such things as barometric pressure, slope and thermals. Moreover, drones are repairable and upgradeable (Tripolitsiotis et al., 2017).

Drones for educational purposes are available in two forms: pre-built drones (also known as "commercial off-the-shelf drones" and "ready-to-fly drones") (Tezza et al., 2020) that are ready for flight, and drones that require assembly by the user, known as drone construction kits (also known as "do-it-yourself drones"). Representative examples of pre-built educational drones are: Ryze Tello EDU, Makeblock Airblock for STEAM education, and Parrot Mambo EDU. On the other hand, drone construction kits (e.g., Flybrix, Rotor Riot) resemble educational robotics kits, enabling the user to experiment and create various constructions and designs, while their use in education has been extensively studied through the use of Lego NXT, Toyobo, and Gogo board (Ng & Cheng, 2019).

Drone operation is achieved through flight controller, joystick, smart mobile devices (i.e., smartphone, tablet), computer, as well as facial, body or hand gestures (Tezza et al., 2020). One of their distinctive features is that they can be programmed with the purpose of performing an autonomous flight. This can be realized with the use of various visual block-based programming environments (e.g., Scratch, Dronely, Blockly), which are appropriate for beginners (Chevalier et al., 2016; Tilley & Gray, 2017) and facilitate the explanation of many programming concepts (e.g., loops, conditions, variables, sequences). Thus, manufacturers and developers provide mobile apps which not only allow programming but also enable the user to fly the drone in simulation. These applications (mobile apps) are available for people over the age of five, some representative examples being Tynker, Tello EDU and DroneBlocks. Finally, platforms, mobile apps and MOOCs (Bertrand et al., 2018) have been created for teachers and contain activities, suggestions and examples of use in formal or informal learning environments (e.g., DroneBlocks, Tello EDU, Tynker).

## 14.3 Theoretical Framework

In order to explain pre-service and in-service teachers' attitudes, beliefs and perceptions towards ICT and Robotics, a variety of theories and models consisting of different sets of psychological factors have been used and adopted. Examples of these theories and models are the Theory of Planned Behavior (TPB) (Ajzen, 1991), the Technology Acceptance Model (TAM), TAM 2 and TAM 3 (Davis, 1989; Venkatesh & Bala, 2008; Venkatesh & Davis, 2000; Venkatesh et al., 2003). Two of the most widely used models are TAM (Davis, 1989) with its extensions (i.e., TAM 2, TAM 3) and TPB. These two models were adopted from the Theory of Reasoned Action (TRA) (Ajzen & Fishbein, 1980).

According to TAM, two beliefs play an important role in the acceptance of any technology. These are perceived usefulness and perceived ease of use. The belief of perceived usefulness is the "degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, p. 320), while the belief of perceived ease of use is "the degree to which a person believes that using a particular system would be free from effort" (Davis, 1989, p. 320). Both beliefs affect the attitudes towards using the system. Attitude is defined as "the individual's positive or negative evaluation of performing the behavior" (Ajzen & Fishbein, 1980, p. 6). Furthermore, these attitudes determine intentions which in turn affect actual system use. Recent meta-analyses of TAM studies on the intention of teachers to implement ICT in their teaching have indicated that it constitutes a valid model (Scherer & Teo, 2019; Scherer et al., 2019). Since this study investigated the beliefs of pre-service and in-service teachers regarding the perceived advantages and disadvantages of using drones in teaching, as well as the beliefs regarding the factors that facilitate this use, TAM may not have been comprehensive enough to identify these beliefs. TPB was considered the most appropriate theoretical framework.

According to TPB, intention is explained by attitude and two other factors: subjective norm and perceived behavioral control (Ajzen, 2020). Subjective norm is "the person's perception of the social pressures put on him to perform or not perform the behavior in question" (Ajzen & Fishbein, 1980, p. 6), while perceived behavioral control is defined as the individual's perception regarding the ease or difficulty of performing the behavior (Ajzen, 1991). Furthermore, the theory claims that the factors that determine attitude towards behavior, subjective norm and perceived behavioral control are the behavioral, normative and control beliefs respectively. According to Ajzen (2020), a behavioral belief is "the person's subjective probability that performing a behavior of interest will lead to a certain outcome or provide a certain experience" (Ajzen, 2020, p. 315). In addition, Ajzen (1991) supports, based on normative beliefs, that "a person who believes that most referents with whom he is motivated to comply think he should perform the behavior will perceive social pressure to do so" (Ajzen, 1991, p. 7). Finally, control beliefs are related to the presence of factors and conditions which facilitate the performance of the behavior or not (e.g., skills, availability of time, resources) (Ajzen, 2020). In this study, we consider that behavioral and control beliefs are important for the adoption of drones in future classrooms.

Previously, researchers have used TPB or its extensions (e.g., Teo et al., 2016) to investigate educators' attitudes, beliefs and intentions to use various digital technologies in their teaching (Chien et al., 2014; Sadaf et al., 2012; Sadaf & Johnson, 2017; Smarkola, 2008; Sungur-Gul & Huseyin, 2021; Teo & Lee, 2010; Watson & Rockinson-Szapkiw, 2021). For example, Smarkola (2008) used TAM and TPB to investigate pre-service and experienced teachers' beliefs which contribute to their intentions to use ICT in their teaching. In another study, Sadaf et al. (2012) examined pre-service teachers' behavioral, normative, and control beliefs regarding their intentions of future use of Web 2.0 technologies in their teaching. Similarly, Sadaf and Johnson (2017) used the conceptual framework of TPB in order to explore teachers' behavioral, normative, and control beliefs related to digital literacy integration into their classrooms. More recently, Sungur-Gul and Huseyin (2021) used TPB to explain pre-service teachers' mobile learning readiness. Watson and Rockinson-Szapkiw (2021) examined pre-service teachers' intention to use technology-enabled learning, while Chien et al. (2014) used variables of decomposed TPB to explore teachers' beliefs about technology-based assessments in classrooms.

Given the power of TPB in explaining how teachers' beliefs could contribute to their intentions of using digital technologies, variables of this theory were used as the conceptual framework of this study. More specifically, in this study we hypothesized that in order for pre-service and in-service teachers to use drones in their teaching, we must consider that these will help their teaching by offering specific advantages for them and their students (i.e., behavioral beliefs). In addition, we hypothesized that in order for pre-service and in-service teachers to use drones in their teaching, they need to feel that they have all the factors (e.g., time, support, and training) that can facilitate its use (i.e., control beliefs). Therefore, by measuring pre-service and in-service teachers' beliefs, it can be explored why they hold specific attitudes and perceptions towards the use of drones in teaching. Furthermore, we used intention and attitude, which are common variables in TAM and TPB.

### *14.3.1 Pre-service and In-service Teachers and Robotics*

Despite the growing interest in educational robotics, there is a lack of studies investigating pre-service and in-service teachers' attitudes, beliefs and perceptions towards the use of robots in teaching (Tang et al., 2020). Following a review of the literature, two categories of studies were identified. The first category comprises research in which the sample was informed about the attributes and affordances of educational robots through presentations, websites, articles and videos. In these studies, the sample did not have the opportunity to interact with the robots. The second category comprises research where the sample interacted with the robots and conducted a number of activities with them. The most relevant studies of both categories are presented below.

Khanlari and Mansourkiaie (2015) explored in their study the perceptions of 11 in-service teachers of primary education regarding the use of robots in the context of STEM learning. The sample had little to no experience in educational robotics; therefore, to accustom them, the researchers created a website that contained articles and videos about educational robotics. Once the teachers studied the material, they answered an online questionnaire. The findings of this study indicated that most teachers want to integrate robots in their teaching activities. They also recognized that "… robotics is a useful educational tool for primary grades…". On the other hand, a number of teachers mentioned that, while they are familiar with robotics, they avoid implementing it in teaching because it makes them anxious. Subjects in which teachers mentioned they would use robots were Mathematics, Science and Geometry, while they stated that their use will improve technology literacy in primary education.

Another study, by Khanlari (2015), investigated the beliefs, the barriers as well as the support that teachers perceive they require in order to use robotics in the classroom. Eleven in-service teachers of primary education with no prior knowledge of educational robotics participated in the study. As with the previous study, this study made use of a website that contained articles and videos on educational robotics in order to inform the teachers. Next, teachers answered an online questionnaire. Khanlari (2015) found out teachers believe they need to be trained to integrate robotics into their teaching. In addition, teachers believe that robots help to develop various skills in pupils, such as mathematical reasoning, and problem-solving and several lifelong skills (e.g., critical thinking, cooperation, decision making, creativity), as well as to improve communication skills. As obstacles, teachers mentioned a lack of educational robots in school, infrastructure problems, time-consuming procedure for the integration of drones in the classroom, a lack of technical and instructional support, and the fact that they do not feel confident enough to use this technology in their classes.

In another study, Reich-Stiebert and Eyssel (2016) investigated teachers' attitudes, predictors of attitudes, and preferred application areas regarding educational robots. The sample was 59 primary and secondary education teachers with little experience in educational robots. The researchers made a short presentation of the features and functions of educational robots and showed teachers pictures of the humanoid robot NAO. Data collection was done through questionnaire. The results showed that teachers' attitudes ranged from neutral to negative regarding teaching and learning with the use of educational robots. Furthermore, they mentioned that they would use robots in the subjects of Informatics, Mathematics and Physics. However, they were neutral regarding their use in the subjects of Biology, Chemistry, Geography, History and Foreign Languages.

In their study, Kennedy et al. (2016) investigated teachers' attitudes, willingness and factors that influence engagement with educational robots. The sample consisted of non-educators as well as 35 in-service teachers of primary education. The sample saw various pictures of the NAO humanoid robot and subsequently answered to a questionnaire which measured attitudes and willingness to use robots. The results showed that teachers are cautious but potentially accepting to use educational robots.

What follows are indicative studies in which the sample had the opportunity to interact with the robots. Fridin and Belokopytov (2014) investigated the first-time acceptance of robots. The sample consisted of 18 pre-school and elementary teachers who participated in a professional workshop on educational robots. A number of teachers had an interaction with the NAO robot, while others observed the procedure. Data collection was done with the use of a questionnaire that was created according to the Unified Theory of Acceptance and Use of Technology (UTAUT). The findings indicated that teachers generally accept that a human-like robot can function as an interactive tool in teaching.

In another study, Chevalier et al. (2016) investigated the perceptions of 43 in-service teachers of primary and secondary education regarding educational robotics. They participated in the study in the context of robotics teacher training sessions and used the Thymio II robot. The data collection was done using a questionnaire. The results showed that teachers believed that the robot allowed pupils to acquire knowledge. The subjects they would choose to teach using a robot were: Mathematics, Science, General Education, Art and, to a lesser extent, Languages and Physical Education. The results also showed that teachers believe that, via utilization of the robots, pupils can develop certain skills that are related to learning strategies, creative thinking, communication, collaboration and reflective process.

In their study, Kim and Lee (2016) examined how robot programming education affects teachers' attitudes towards robots. The sample consisted of 40 pre-service teachers who were divided into a control group and an experimental group, in the context of a robot programming class. The participants in the experimental group interacted with Lego Mindstorms EV3 robots, assembled them, programmed them via block-based programming and conducted assignments that were based on their sensors. Data collection was done with the use of a questionnaire. The results showed that, even though the pre-tests of the experimental group revealed negative attitudes towards robots, the post-tests revealed significantly more positive outcomes.

In a more recent study, Khanlari (2019) conducted a workshop with the aim of investigating the perceptions of teachers regarding the use of robotics in STEM education and whether it will foster positive attitudes towards STEM careers. The sample of this study consisted of 58 in-service teachers of primary education that had no prior knowledge of educational robotics. Teachers engaged in hands-on robotics activities using preassembled Lego Mindstorms and were subsequently asked to program and make calculations with the robot. Data collection was done using pre/post questionnaires that measured attitudes and perceptions. The results indicated that the teachers had initially negative perceptions on the effects of robotics (48%), while after their interaction with the robots they had more positive perceptions (78%). Furthermore, the results indicated that participants had positive attitudes regarding the use of robots in STEM disciplines, e.g., Mathematics and Science. Also, among other things, the teachers mentioned that the pupils, through their involvement with

Lego Mindstorms, will acquire technological literacy, mathematical reasoning and problem-solving skills.

In their study, Sisman and Kucuk (2019) investigated teachers' perceptions and experiences regarding their use of educational robotics. 30 pre-service elementary teachers participated in the study, in the context of an educational robotics course. Data collection was done through survey, observation and interviews. The participants were asked to assemble robotic designs (e.g., chick, owl, bull, dog robots) using educational robotics kits. The results showed that the participants had an increased level of collaboration, satisfaction, enjoyment and motivation.

Based on the literature review above, several conclusions can be drawn. Firstly, there is a limited number of studies that focus on attitudes, beliefs and perceptions of teachers towards the use of robots in teaching. Secondly, according to the findings of existing studies, the majority of teachers show positive intentions (Khanlari, 2015; Khanlari & Mansourkiaie, 2015)—with some exceptions—regarding the use of robots in teaching. Thirdly, while a number of teachers initially appear to have a neutral or even negative attitude towards robots, after hands-on interaction with them, they show a change in attitude (Kennedy et al., 2016; Khanlari, 2019; Kim & Lee, 2016). Of particular interest is the fact that even the teachers who have a negative attitude towards robots still acknowledge the benefits of their use in the classroom, the benefits they offer to students, and the subjects which would be most suitable for their implementation (Kim & Lee, 2016; Reich-Stiebert & Eyssel, 2016). The above-mentioned studies also show a number of limitations regarding the use of robots in education, the most important of which relate to the lack of teacher training programs as well as the lack of educational robots in schools.

TPB will contribute to the better understanding of the factors that influence the beliefs of pre-service and in-service teachers in the use of robots in education. In conclusion, the review of the literature confirms the research gap, since, to the best of our knowledge, no study has investigated pre-service and in-service teachers' attitudes, beliefs and perceptions towards using aerial educational robotics in teaching.

## 14.4 Methodology

### *14.4.1 Elicitation Study*

As mentioned in a previous section, among the objectives of this study was to investigate pre-service and in-service teachers' behavioral and control beliefs regarding the use of drones in teaching and learning, as well as their perceptions regarding the skills that can be developed through the use of drones in teaching and learning and the subjects in which drones can be used. In order to develop the questionnaire regarding these beliefs and skills, an elicitation study was conducted involving 15 pre-service teachers and 18 in-service teachers who voluntarily participated in the study. All participants had experience with the use of drones for educational purposes and were excluded from the main study. The elicitation study was conducted according to the guidelines suggested by Ajzen and Fishbein (1980, p. 261) and Ajzen (2020). More specifically, participants were asked to answer the following questions of an online open-ended questionnaire: (a1) What do you view as the advantages of using drones in your teaching? (a2) What do you view as the disadvantages of using drones in your teaching? (behavioral beliefs), (b1) What factors or circumstances make it easier for you to use drones in your teaching? (b2) What factors or circumstances make it more difficult for you to use drones in your teaching? (control beliefs), (c) Which skills do you believe can be developed using drones in students' learning, and (d) What do you believe are the school subjects in which drones can be used?

Two researchers in ICT in education independently coded the generated behavioral and control beliefs and perceptions for skills and subjects. Their results of coding and the classification of the answers indicated a satisfactory agreement which ranged from 85 to 93%. This elicitation study resulted in the development of 46 closed-ended items: (a) 20 items regarding behavioral beliefs, (b) 9 items regarding control beliefs, (c) 9 perceptions regarding skills, and (d) 8 perceptions regarding subjects. These beliefs and perceptions were then tested and modified through a pilot study with the participants of the elicitation study. The latest version of beliefs and perceptions items was used in the questionnaire of the main study.

## *14.4.2 Main Study*

### 14.4.2.1 Participants

The participants (n = 181) of this study were both pre-service (n = 80, 44.2%) and in-service teachers (n = 101, 55.8%) of primary education. Pre-service teachers were enrolled in a compulsory "Information and Communications Technologies in Education" course at the Faculty of Primary Education of the National and Kapodistrian University of Athens. In-service teachers were enrolled in postgraduate courses and seminars on ICT in education and online learning at the same university. All the participants voluntarily signed up to participate in this study. Among these participants, 144 (79.6%) were female and 37 (20.4%) were male. Table 14.1 summarizes the descriptive statistics of the participants.

### 14.4.2.2 Instruments

Data was collected by an online questionnaire, which consisted of two main parts. The first part referred to the participants' demographics (i.e., gender, age). The second part was divided into six sections. Sections 14.2.3 and 14.2.4 contained the scales of intention and attitude toward the use of drones in teaching respectively.

**Table 14.1** Descriptive statistics of the participants

| | Pre-service teachers | | In-service teachers | |
|---|---|---|---|---|
| | N | % | N | % |
| *Gender* | | | | |
| Male | 12 | 15 | 25 | 24.8 |
| Female | 68 | 85 | 76 | 75.2 |
| *Age* | | | | |
| ≤25 | 75 | 93.8 | 0 | 0 |
| 26–35 | 3 | 3.8 | 52 | 51.5 |
| 36–45 | 2 | 2.5 | 37 | 36.6 |
| ≥46 | 0 | 0 | 12 | 11.9 |

Sections 14.2.5 and 14.2.6 contained items of behavioral and control beliefs respectively, while Sects. 14.2.7 and 14.2.8 contained items of perceptions. The items used in Sects. 14.2.4, 14.2.5, 14.2.6 and 14.2.7 of the questionnaire were based on the beliefs and perceptions identified in the elicitation study. The items used in the study are shown in the tables in the following section.

#### 14.4.2.3 Intention

Participants' intention to use drones in their teaching was measured using a 3-item scale adopted from Ajzen (1991). These items were (a) "I intend to use drones in my teaching in the future", (b) "I will try to use drones in my teaching in the future" and (c) "I plan to use drones in my teaching in the future". All items were rated on a 5-point Likert-type scale (from 1 = Strongly disagree to 5 = Strongly agree). The factorial analysis supported the unidimensional structure of the construct (Principal Axis Factoring led to a one-factor solution, accounting for the 77.98% of variance), while Cronbach's α value supported its reliability ($\alpha = 0.847$). Thus, the 3 items were averaged to yield a measure of intention in which a higher score indicates a strong intention to use drones in teaching.

#### 14.4.2.4 Attitude

The participants' attitude towards the use of drones in their teaching was measured using a semantic differential scale adopted from Ajzen and Fishbein (1980, p. 261) and Ajzen (2020). More specifically, participants were asked to rate the use of drones in their teaching on a set of five 5-point polar adjective scales with end-points of (a) Harmful/Beneficial, (b) Unpleasant/Pleasant, (c) Bad/Good, (d) Worthless/Valuable, and (e) Unenjoyable/Enjoyable. The factorial analysis supported the unidimensional structure of the construct (Principal Axis Factoring led to a one-factor solution, accounting for the 72.70% of variance), while Cronbach's α value supported its reliability (α = 0.906). Hence, the five adjective scales were averaged to create a measure of attitude in which a higher score indicates positive attitudes towards the use of drones in teaching.

#### 14.4.2.5 Behavioral Beliefs

Participants' behavioral beliefs were measured by 20 items based on the results of the elicitation study (see Table 14.3). These items represent different advantages and disadvantages of drones in teaching and learning and are not considered a unidimensional construct. The 20 items were rated on a 5-point Likert-type scale (from 1 = Strongly disagree to 5 = Strongly agree).

#### 14.4.2.6 Control Beliefs

Participants' control beliefs were measured by 9 items regarding various factors or circumstances which facilitate them to use drones in their teaching (see Table 14.4). These items were identified in the elicitation study and were rated on a 5-point Likert-type scale (from 1 = Strongly disagree to 5 = Strongly agree). As in the case of behavioral beliefs, the items of this section were not considered a unidimensional construct.

#### 14.4.2.7 Perceptions on the Skills

Participants' perceptions on the skills that can be developed using drones in teaching were measured by 9 items (see Table 14.7). These items reflect different perceptions for skills and, therefore, were not a unidimensional construct. These 9 perceptions were also obtained from the elicitation study and were rated on a 5-point Likert-type scale (from 1 = Strongly disagree to 5 = Strongly agree).

#### 14.4.2.8 Perceptions on Subjects

Participants' perceptions on the subjects in the teaching of which drones can be used were identified in the elicitation study and were measured using 8 items/subjects (see Table 14.8). The question in this section was "In which of the following subjects do you believe drones can be used in order to further assist your teaching?" Participants were asked to rate the 8 subjects of this question on a 5-point Likert scale (from 1 = Strongly disagree to 5 = Strongly agree).

A pretest for the validity of the questionnaire was conducted by three academic experts in ICT in education to ensure its clarity and comprehensibility. In addition, a pilot study was conducted by 8 pre-service teachers and 12 in-service teachers. These participants were asked to make comments and suggestions regarding the length of the questionnaire as well as the comprehensibility of the items. Few modifications of the wording and the beliefs and perceptions items sequence were made according to the above-mentioned participants' feedback. The required time to complete the questionnaire was approximately 7 min. All items were presented in the Greek language.

#### 14.4.2.9 Procedure

The study took place in the academic year 2020–2021 and was conducted in four phases. In the first phase, after taking the necessary COVID-19 measures, the participants attended, in small groups of 20 persons, a one-hour presentation on drones, their capabilities, the methods used to operate them, as well as all the fields in which they are used today. In the second phase, the participants were instructed on the use of drones. Then, they interacted with four types of drones, through assembling, programming, simulating and flying them. More specifically, the interaction was accomplished in three stages. In the first stage, the participants were asked to form groups of two and assemble a drone, using the drone kits available. In the second stage, they were asked to create a code in a block-based programming language with the help of the DroneBlocks simulation application (DroneBlocks, 2021). In the third stage, the participants were asked to fly the drones in the university's outdoor area. In the final phase, the participants completed the online questionnaire. The duration of the second and third phase ranged from 3 to 4 h for each participant.

#### 14.4.2.10 Drones Used in the Study

The drones used for the purpose of the research combine such features and abilities as to be representative of the average drone available today. In the beginning, the pre-built Parrot Bebop 2 quadcopter (Parrot, 2021) was chosen, which has a built-in camera and GPS. Then, the pre-built quadcopter Ryze Tello EDU (DJI, 2021) was chosen, which has a built-in camera, as well as the Makeblock Airblock STEAM drone (Makeblock, 2021), which has magnetically detachable rotors that allow it to take different forms (e.g., dualcopter, tricopter, quadcopter, hexacopter). These two drones provide access to mobile apps for programming, simulation and flight. Finally, a drone construction kit was chosen, namely the Flybrix Drone Kit (Flybrix, 2021). A total of four drones of each type were used (16 models in total), while there were additional batteries available for each drone model.

### 14.4.3 Statistical Analyses

All analyses were carried out in SPSS 25 for Microsoft Windows. The scale data (i.e., intention and attitudes) were tested for normality using the Kolmogorov-Smirnov test. The results showed that the data were not in normal distribution. Therefore, in order to find whether there were any statistically significant differences between pre-service and in-service teachers regarding these variables and the remaining variables that are all ordinal (namely, behavioral and control beliefs and perceptions), we employed the non-parametric Mann–Whitney *U* test. In addition, to examine if there was a statistically significant correlation between participants' intentions and attitudes, as well as between their intentions and behavioral and control beliefs regarding the use of drones in teaching and learning, Kendall's $\tau_B$ correlation coefficient was used.

## 14.5 Results

### 14.5.1 Intention and Attitudes of Pre-service and In-service Teachers

As we have seen, one of the research questions of this study related to pre-service and in-service teachers' intentions and attitudes towards the use of drones in their teaching. Table 14.2 shows the mean values (M) and standard deviations (SD) of these two scales. As can be seen, the mean values are above 4, thereby indicating positive attitudes and intentions towards using drones in teaching. Concerning the differences between the two groups of participants, the results of the Mann–Whitney U test presented in Table 14.2 indicate that there was a statistically significant difference between pre-service and in-service teachers' intention. This indicates that pre-service teachers had a significantly stronger intention to use drones in their teaching in the future than in-service teachers. Furthermore, Kendall's correlation coefficients showed that there was a positive relationship between pre-service ($\tau_b = 0.496$, $p = 0.000$) and in-service teachers' ($\tau_b = 0.474$, $p = 0.000$) attitudes and their intentions.

**Table 14.2** Means (M), standard deviations (SD) and Mann–Whitney U test of pre-service and in-service teachers' attitude and intention

| Scales | Overall | | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | | |
| Intention | 4.31 | 0.664 | 4.39 | 0.731 | 4.24 | 0.602 | 3286.500 | 0.028* |
| Attitude | 4.47 | 0.644 | 4.51 | 0.669 | 4.44 | 0.625 | 3582.000 | 0.182 |

* The mean difference is significant at the 0.05 level

This suggest that, when attitudes towards using drones in teaching increases, then intention to use drones also increases.

### 14.5.2 Behavioral and Control Beliefs

Another research question of this study related to participants' behavioral and control beliefs. Tables 14.3 and 14.4 shows the 20 behavioral and 9 control beliefs respectively which were identified in the elicitation study and measured in the main study. More specifically, Table 14.3 shows that the behavioral beliefs are related to the various advantages and disadvantages of using drones in future classrooms. Inspection of the values per behavioral belief item in Table 14.3 indicates that participants of this study evaluated very highly in all behavioral beliefs regarding the advantages of drones in teaching. In addition, they evaluated lowly in all behavioral beliefs regarding the disadvantages of drones (see items 14–20). These results in the majority of items indicate that, on average, participants had positive to strongly positive beliefs regarding the use of drones in teaching. Importantly enough, pre-service teachers had the highest mean score in all items regarding the advantages of drones as well as the lowest mean score in all items regarding the disadvantages of drones compared to in-service teachers.

Table 14.3 also presents the results of Mann–Whitney's U. As we can see, statistically significant differences were found in 6 of the 20 behavioral belief items. In all of the behavioral belief items regarding the advantages, pre-service teachers had significantly higher values than in-service teachers (see items 1, 2, 3, 5, 6, 7, 10). In contrast, in-service teachers had significantly higher values in behavioral beliefs regarding the disadvantages of drones in teaching.

Table 14.4 shows the control beliefs identified in this study. These consisted of four groups of factors of circumstances which related to: (a) support from head teachers and colleagues, (b) financial issues and availability of drones, (c) training opportunities, (d) and time and legal issues. The descriptive analysis shows that these beliefs were evaluated very high, which indicates that participants believed that the availability of these factors of circumstances would facilitate the use of drones in teaching. Among these beliefs were those that were related to training in drone use as well as training on the integration of drones in teaching. The results of Mann–Whitney's U show that there was statistically significant difference between the two groups of participants in 4 of the 9 control beliefs. Pre-service teachers' mean scores on the beliefs "My training in the use of drones" and "My training on how to integrate drones in my teaching" were significantly higher than in-service teachers' mean scores. On the contrary, in-service teachers had statistically higher mean scores than pre-service teachers on the beliefs which related to head teacher support and availability of drones in schools.

Behavioral and control beliefs were analyzed further. Each belief was correlated with intention. As mentioned in a previous section, correlation was measured using Kendall's correlation coefficients. These correlations are presented in Tables 14.5 and

**Table 14.3** Median (Mdn), Mean scores (M) and Standard Deviations (SD) for behavioral belief items: comparison of pre-service teachers and in-service teachers

| The use of drones in my teaching will | Pre-service teachers | In-service teachers | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | Mdn | | M | SD | M | SD | | |
| 1. Promote cooperative teaching | 5.00 | 4.00 | 4.55 | 0.727 | 4.31 | 0.644 | 3086.500 | 0.002* |
| 2. Promote the interdisciplinary approach of knowledge | 5.00 | 4.00 | 4.56 | 0.653 | 4.37 | 0.595 | 3245.500 | 0.010* |
| 3. Promote learning by doing | 5.00 | 5.00 | 4.69 | 0.493 | 4.52 | 0.593 | 3493.500 | 0.064 |
| 4. Promote inquiry-based learning | 5.00 | 5.00 | 4.58 | 0.591 | 4.58 | 0.534 | 4015.500 | 0.934 |
| 5. Make my lesson more fun for me | 5.00 | 5.00 | 4.59 | 0.758 | 4.47 | 0.593 | 3384.000 | 0.030* |
| 6. Make my lesson more fun for pupils | 5.00 | 5.00 | 4.69 | 0.493 | 4.64 | 0.540 | 3912.500 | 0.652 |
| 7. Make my lesson more pleasant for me | 5.00 | 4.00 | 4.64 | 0.733 | 4.41 | 0.619 | 3046.500 | 0.001* |
| 8. Make my lesson more interesting for pupils | 5.00 | 5.00 | 4.66 | 0.502 | 4.54 | 0.557 | 3615.500 | 0.152 |
| 9. Increase pupils' learning motivation | 5.00 | 5.00 | 4.56 | 0.524 | 4.47 | 0.576 | 3714.000 | 0.286 |
| 10. Increase pupils' interest for learning | 5.00 | 4.00 | 4.61 | 0.562 | 4.45 | 0.574 | 3394.500 | 0.034** |
| 11. Enhance pupils' knowledge | 4.50 | 4.00 | 4.40 | 0.686 | 4.36 | 0.642 | 3840.500 | 0.526 |
| 12. Encourage pupils' creativity | 5.00 | 5.00 | 4.58 | 0.591 | 4.50 | 0.610 | 3793.000 | 0.415 |
| 13. Help pupils to improve their spatial skills | 5.00 | 5.00 | 4.61 | 0.562 | 4.54 | 0.592 | 3805.500 | 0.431 |
| 14. Make preparing for lessons more time-consuming** | 2.00 | 2.00 | 1.75 | 0.666 | 2.00 | 0.812 | 3372.500 | 0.039* |

(continued)

**Table 14.3** (continued)

| The use of drones in my teaching will | Pre-service teachers | In-service teachers | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | Mdn | | M | SD | M | SD | | |
| 15. Require additional training on my part** | 2.00 | 2.00 | 1.75 | 0.646 | 1.81 | 0.717 | 3884.500 | 0.627 |
| 16. Require that I acquire knowledge in problem-solving techniques** | 2.00 | 2.00 | 1.90 | 0.668 | 1.99 | 0.818 | 3802.500 | 0.465 |
| 17. Require time for pupils to become familiar with the drone** | 2.00 | 2.00 | 2.01 | 0.720 | 2.08 | 0.845 | 3945.500 | 0.771 |
| 18. Infringe personal data** | 3.00 | 3.00 | 3.01 | 0.934 | 3.40 | 0.928 | 3170.000 | 0.008* |
| 19. Make me anxious** | 3.00 | 3.00 | 2.68 | 0.925 | 3.25 | 0.963 | 2770.000 | 0.000* |
| 20. Require additional attention to avoid pupils' injuries** | 2.00 | 3.00 | 1.99 | 0.819 | 2.63 | 1.017 | 2611.000 | 0.000* |

* The mean difference is significant at the 0.05 level
** Items for which the scoring was reversed

14.6, regarding behavioral beliefs and control beliefs respectively. As we can see in Table 14.5, many of the behavioral beliefs significantly correlated with participants' intention. Therefore, these correlation results show that the participants who had positive perceptions towards the advantages that drones will have in teaching were likely to have more strong intention regarding the of use drones in their teaching.

As indicated in Table 14.6, 4 of 9 pre-service teachers' control beliefs and 2 of 9 in-service teachers' control beliefs correlated with their intention to use drones in their future classrooms. Pre-service teachers' beliefs were the ones that were related to training in the use of drones, time availability, and head teacher and colleagues' support, while in-service teachers control beliefs were those that were related to training in the use of drones and availability of drones in their schools. These positive correlations suggest that, when pre-service and in-service teachers' beliefs regarding the factors or circumstances which facilitate the use of drones in teaching and learning increase, then their intention to use drones also increases.

**Table 14.4** Median (Mdn), Mean scores (M) and Standard Deviations (SD) for control belief items: comparison of pre-service teachers and in-service teachers

| What factors or circumstances make it easier for you to use drones in your teaching? | Pre-service teachers | In-service teachers | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | Mdn | | M | SD | M | SD | | |
| 1. My training in the use of drones | 5.00 | 4.00 | 4.70 | 0.582 | 4.43 | 0.572 | 2936.500 | 0.000* |
| 2. My training on how to integrate drones into my teaching | 5.00 | 4.00 | 4.69 | 0.466 | 4.37 | 0.717 | 3112.500 | 0.002* |
| 3. Cost reduction of drones | 4.00 | 4.00 | 4.09 | 0.983 | 3.90 | 0.911 | 3492.500 | 0.099 |
| 4. Creation of a repository of good practices of drone utilization | 4.00 | 4.00 | 4.06 | 0.847 | 4.17 | 0.775 | 3779.000 | 0.425 |
| 5. Establishment of a legal framework regarding the use of drones in school | 4.00 | 4.00 | 4.03 | 0.914 | 3.88 | 0.898 | 3666.000 | 0.261 |
| 6. Time available for the preparation of my lesson | 4.00 | 4.00 | 4.19 | 0.731 | 4.11 | 0.747 | 3822.500 | 0.502 |
| 7. Support from the school's head teacher | 4.00 | 5.00 | 4.10 | 0.836 | 4.36 | 0.756 | 3352.000 | 0.034* |
| 8. Support from my colleagues at school | 4.00 | 4.00 | 3.94 | 0.817 | 3.74 | 0.868 | 3566.500 | 0.152 |

(continued)

**Table 14.4** (continued)

| What factors or circumstances make it easier for you to use drones in your teaching? | Pre-service teachers | In-service teachers | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | Mdn | | M | SD | M | SD | | |
| 9. Availability of drones in school | 5.00 | 5.00 | 4.34 | 0.779 | 4.63 | 0.578 | 3258.000 | 0.010* |

* The mean difference is significant at the 0.05 level

### *14.5.3 Skills Developed Through the Use of Drones During Teaching and Learning*

Another research question of this study related to pre-service and in-service teachers' perceptions regarding the skills that can be developed using drones in teaching and learning. Table 14.7 presents these perceptions. The mean values for both participants' groups are over 4, indicating that the majority of them believed that the use of drones will improve pupils' various skills. Analysis indicated that participants had the most positive perceptions towards certain skills such as: spatial skills, digital skills, creativity and basic programming principles. The results of Mann–Whitney's U showed that, in digital skills and creativity, pre-service teachers had statistically significant positive perceptions compared to in-service teachers.

### *14.5.4 Subjects in Which Drones Can Be Used*

As we have seen, another research question of the current study related to participants' perceptions regarding the subjects that drones can be used in teaching. Table 14.8 presents the results related to this research question. As seen in this table, the results indicate that pre-service and in-service teachers had more positive perceptions regarding drone use in the subjects of Physics, Mathematics, Geography, Technology and Environmental Education. In contrast, they had less positive perceptions regarding drone use in the subjects of Physical Education, History, Art and Theatre Education. Furthermore, the results of Mann–Whitney's U showed that there were statistically important differences between the groups of the participants in the subjects of Physics, Theatre Education and Environmental Education. In these subjects, pre-service teachers had higher mean scores compared to in-service teachers.

**Table 14.5** Kendall's correlation for pre-service and in-service teachers' intention and behavioral beliefs

| The use of drones in my teaching will | Pre-service teachers | In-service teachers |
|---|---|---|
| | Intention | Intention |
| 1. Promote cooperative teaching | 0.650** (0.000) | 0.451** (0.000) |
| 2. Promote the interdisciplinary approach of knowledge | 0.553** (0.000) | 0.434** (0.000) |
| 3. Promote learning by doing | 0.375** (0.000) | 0.243** (0.005) |
| 4. Promote inquiry-based learning | 0.227* (0.023) | 0.334** (0.000) |
| 5. Make my lesson more fun for me | 0.239* (0.015) | 0.305** (0.000) |
| 6. Make my lesson more fun for pupils | 0.103 (0.301) | 0.316** (0.000) |
| 7. Make my lesson more pleasant for me | 0.283** (0.004) | 0.440** (0.000) |
| 8. Make my lesson more interesting for pupils | 0.120 (0.229) | 0.232** (0.008) |
| 9. Increase pupils' learning motivation | 0.273** (0.006) | 0.268** (0.002) |
| 10. Increase pupils' interest for learning | 0.282** (0.005) | 0.259** (0.003) |
| 11. Enhance pupils' knowledge | 0.333** (0.001) | 0.373** (0.000) |
| 12. Encourage pupils' creativity | 0.365** (0.000) | 0.420** (0.000) |
| 13. Help pupils to improve their spatial skills | 0.249* (0.012) | 0.314** (0.000) |
| 14. Make preparing for lessons more time-consuming*** | 0.348** (0.000) | 0.141 (0.092) |
| 15. Require additional training on my part*** | 0.323** (0.001) | 0.130 (0.124) |
| 16. Require that I acquire knowledge in problem-solving techniques*** | 0.333** (0.001) | 0.133 (0.101) |
| 17. Require time for pupils to become familiar with the drone*** | 0.151 (0.115) | 0.092 (0.267) |
| 18. Infringe personal data*** | 0.025 (0.792) | 0.014 (0.862) |
| 19. Make me anxious*** | 0.169 (0.069) | 0.091 (0.265) |
| 20. Require additional attention to avoid pupils' injuries*** | 0.145 (0.124) | -0.088 (0.281) |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)
*** Items for which the scoring was reversed

## 14.6 Discussion and Conclusions

Aerial robotics and, particularly, one of its categories, i.e., drones, constitute a new research field in education, which has begun approximately one decade ago. Given that teachers play a key role both in the introduction and in the implementation and continuation of every educational change and innovation (Byker et al., 2017;

**Table 14.6** Kendall's correlation for pre-service and in-service teachers' intention and control beliefs

| What factors or circumstances make it easier for you to use drones in your teaching? | Pre-service teachers | In-service teachers |
|---|---|---|
| | Intention | Intention |
| 1. My training in the use of drones | 0.412** (0.000) | 0.387** (0.000) |
| 2. My training on how to integrate drones into my teaching | 0.125 (0.215) | 0.002 (0.984) |
| 3. Cost reduction of drones | −0.028 (0.764) | −0.041 (0.683) |
| 4. Creation of a repository of good practices of drone utilization | 0.083 (0.378) | −0.009 (0.927) |
| 5. Establishment of a legal framework regarding the use of drones in school | −0.087 (0.356) | −0.033 (0.744) |
| 6. Time availability for the preparation of my lesson | 0.274** (0.004) | −0.029 (0.771) |
| 7. Support from the school's head teacher | 0.313** (0.000) | 0.036 (0.717) |
| 8. Support from my colleagues at school | 0.216* (0.012) | −0.008 (0.939) |
| 9. Availability of drones in school | −0.064 (0.502) | 0.227* (0.022) |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

**Table 14.7** Median (Mdn), Means (M), standard deviations (SD) and Mann–Whitney U test of pre-service and in-service teachers' perceptions regarding the skills that pupils can develop using drones

| Drone use facilitates the development of | Pre-service teachers | In-service teachers | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | Mdn | | M | SD | M | SD | | |
| 1. Digital skills | 5.00 | 5.00 | 4.68 | 0.546 | 4.50 | 0.559 | 3361.000 | 0.023* |
| 2. Spatial skills | 5.00 | 5.00 | 4.70 | 0.560 | 4.62 | 0.526 | 3676.500 | 0.199 |
| 3. Basic programming principles | 5.00 | 5.00 | 4.58 | 0.689 | 4.41 | 0.737 | 3508.000 | 0.081 |
| 4. Problem-solving skills | 5.00 | 4.00 | 4.49 | 0.746 | 4.38 | 0.646 | 3531.000 | 0.103 |
| 5. Critical thinking skills | 5.00 | 4.00 | 4.51 | 0.693 | 4.34 | 0.697 | 3429.500 | 0.051 |
| 6. Social skills | 4.00 | 4.00 | 4.08 | 0.883 | 4.00 | 0.812 | 3807.500 | 0.480 |
| 7. Pupils' self-motivation | 4.50 | 4.00 | 4.35 | 0.781 | 4.25 | 0.607 | 3512.000 | 0.092 |
| 8. Creativity | 5.00 | 4.00 | 4.61 | 0.684 | 4.42 | 0.621 | 3225.000 | 0.008* |

* The mean difference is significant at the 0.05 level

**Table 14.8** Median (Mdn), Means (M), standard deviations (SD) and Mann–Whitney U test of pre-service and in-service teachers' perceptions regarding the subjects in which drones can be used

| In which of the following subjects do you believe drones can be used to further assist your teaching? | Pre-service teachers | In-service teachers | Pre-service teachers | | In-service teachers | | U | *p* |
|---|---|---|---|---|---|---|---|---|
| | Mdn | | M | SD | M | SD | | |
| Physics | 5.00 | 4.00 | 4.75 | 0.436 | 4.28 | 0.736 | 2620.000 | 0.000* |
| Mathematics | 5.00 | 4.00 | 4.31 | 0.894 | 4.30 | 0.807 | 3901.000 | 0.663 |
| Geography | 5.00 | 5.00 | 4.68 | 0.497 | 4.61 | 0.509 | 3789.000 | 0.386 |
| Technology | 5.00 | 5.00 | 4.71 | 0.455 | 4.58 | 0.621 | 3721.000 | 0.263 |
| Physical Education | 3.00 | 3.00 | 3.41 | 1.229 | 3.20 | 0.980 | 3691.500 | 0.297 |
| History | 4.00 | 4.00 | 3.66 | 1.102 | 3.70 | 1.005 | 3958.000 | 0.807 |
| Arts | 4.00 | 3.00 | 3.66 | 0.993 | 3.42 | 0.941 | 3435.500 | 0.069 |
| Theatre Education | 4.00 | 3.00 | 3.63 | 1.023 | 3.22 | 1.055 | 3103.000 | 0.005* |
| Environmental Education | 5.00 | 5.00 | 4.78 | 0.551 | 4.53 | 0.687 | 3262.500 | 0.005* |

* The mean difference is significant at the 0.05 level

Fullan, 2015; Harris & Jones, 2019; Vandeyar, 2017), the current study—through utilization of the theoretical framework of the Theory of Planned Behavior (TPB) (Ajzen, 1991)—has focused on how the potential use of drones in education is viewed by two different groups of participants: in-service teachers and pre-service teachers as future teachers. The results of the study have been encouraging regarding the use of drones in the future, since both groups have positive perceptions towards them. What follows is a discussion on the main results of the study based on its research questions.

### *14.6.1 Pre-service and In-service Teachers' Intention and Attitude*

Concerning the first research question, one important finding is that pre-service and in-service teachers had a strong intention regarding the use of drones in teaching as well as positive attitudes towards said use. According to TPB and TAM, these two variables are among the key factors regarding the acceptance of any technology in education (Gómez-Ramirez et al., 2019; Opoku et al., 2020; Scherer et al., 2019; Scherer & Teo, 2019). The fact that there was a positive correlation between these two variables in the present study suggests that, when pre-service and in-service teachers' attitudes towards using drones in their teaching increases, then their intention to use drones also increases. Therefore, future attempts to integrate aerial robotics in education through drones should focus, among other things, on shaping positive attitudes among teachers towards this use. This finding is in accordance with the results of previous studies regarding the acceptance of various digital technologies in education (Scherer & Teo, 2019; Scherer et al., 2019) as well as regarding the use of ground robots by teachers in education (Bazelais et al., 2017; Schina et al., 2021; Weng et al., 2018).

### *14.6.2 Pre-service and In-service Teachers' Behavioral and Control Beliefs*

Regarding the second research question and the participants' behavioral beliefs, one important finding is that these beliefs relate more to the potential advantages rather than the disadvantages of using drones in teaching and learning. For example, among the advantages which the participants mentioned are that the use of drones in their teaching will make their lessons more fun and pleasant for them, make lessons more interesting for their pupils, and increase pupils' motivation and interest for learning. These beliefs are also supported by previous ICT studies (e.g., Sadaf & Johnson, 2017; Sadaf et al., 2012). Also, another important finding that concerns the third research question is that the majority of these beliefs was correlated with the participants' intention. According to TPB (Ajzen, 1991), the behavioral beliefs result in an either unfavorable or favorable attitude which in turn affects intention. Subsequently, the results of this study suggest that, to improve both the intention of pre-service teachers as future teachers as well as the intention of in-service teachers to use drones in teaching in the context of aerial robotics, educational policy should enhance their attitudes as well as their behavioral beliefs towards the use of drones in schools. In particular, educational policy should focus on the behavioral beliefs that are related to the advantages of drones. Teachers should be encouraged to view drones as making their lessons more beneficial to them and to their pupils.

One more important finding concerning the second and third research question regarding control beliefs is that the participants will use drones in their teaching if they believe that there are conditions and factors which will facilitate said use. According to Ajzen (1991), the control beliefs result in self-efficacy or perception of control over the performance of a specific behavior. Based on the present study's results regarding control beliefs, the most important factors, which are also positively correlated with their intention, are the training in the use of drones and how to integrate them into their teaching, the support from the school's head teacher, and the availability of drones in schools. This finding is similar to that of previous ICT (Sadaf et al., 2012; Smarkola, 2008) and STEM (Castro et al., 2018; Knauder & Koschmieder, 2019; Pimthong & Williams, 2018) studies which indicated that the training and the availability of resources (e.g., hardware, infrastructure) as well as the head teacher's support were positively correlated with educators' stronger intentions to use technology in their teaching. Therefore, the most efficient way to increase pre-service and in-service teachers' intention to use drones in their future classrooms is to provide them with all the facilitating factors and conditions which will be identified by their control beliefs.

### 14.6.3 Pre-service and In-service Teachers' Perceptions on Skills

Regarding the fourth research question, the results showed that participants believe that drones in the context of aerial robotics can enhance various skills of pupils. Among the skills which they believe can be enhanced more are: spatial skills, digital skills, problem-solving skills, critical thinking skills, skills of basic programming principles, and creativity skills. Similar skills have been found in previous studies on both robotics and STEM (Atmatzidou et al., 2017; Çalişkan, 2020; Di Battista et al., 2020). Therefore, educational policy regarding aerial robotics in schools should focus on how teachers can be trained to develop the above skills in their pupils.

### 14.6.4 Pre-service and In-service Teachers' Perceptions on Subjects

The results that relate to the fifth research question showed that the participants believed that the use of drones could be implemented either in STEM-related subjects or in Humanities-related subjects. The aforementioned results are in line with those of earlier studies regarding teachers' perceptions on the use of ground robots (Khanlari & Mansourkiaie, 2015; Reich-Stiebert & Eyssel, 2016). These results show that drones could be used in almost every subject of primary education and possibly by all teachers depending on their interests and specialization. More specifically, all the characteristics of drones relate to Science, Technology, Engineering and Mathematics (STEM) (Chen et al., 2019; Chou, 2018; Goodnough et al., 2019). They can be constructed, assembled, and programmed to fly and collect various data through their technical affordances and sensors (Bermúdez et al., 2019; Carnahan et al., 2016; Ng & Cheng, 2019). Therefore, teachers should be encouraged to integrate drones either in STEM-related subjects or in Humanities-related subjects and be provided with specific teaching examples and best teaching practices.

### 14.6.5 Differences Between Pre-service and In-service Teachers' Intentions, Attitudes, Beliefs and Perceptions

Another important finding of this study, which concerns the sixth research question, is that pre-service teachers had a statistically significant stronger intention and more positive attitudes and behavioral beliefs regarding the use of drones in education compared to in-service teachers. They also had more positive perceptions on the skills that can be developed through the use of drones as well as the subjects in which they can be used. This may be due to the fact that today's generation of pre-service teachers is more accustomed to digital technologies and emerging technologies compared to today's in-service teachers (Chiner et al., 2019; Papadakis et al., 2021; Saltan & Arslan, 2017). Another explanation is that in-service teachers have more teaching experience and, very often, their attempts to use digital technologies in their classrooms are related to various factors (e.g., time, resources, support). This means that experienced teachers have a better understanding of how difficult it is to integrate an intervention in schools. Therefore, one would not expect in-service teachers to be more enthusiastic regarding the use of drones compared to pre-service teachers, who are not familiar with real school situations.

In addition, this study showed significant differences between pre-service and in-service teachers in terms of their control beliefs. More specifically, the results indicated that pre-service teachers need more training than in-service teachers. Therefore, training programs for pre-service teachers should assist them not only in how to use drones but also in how to integrate them effectively in their teaching practices. Furthermore, the results showed that in-service teachers need more support from head teachers as well as a greater availability of drones in schools. This finding agrees with the findings of previous studies in education which showed that the role of head teachers is significant regarding the integration of any innovation and change in schools (Fullan, 2015; Jogezai et al., 2021; Mei Wei et al., 2016; Tondeur et al., 2008).

### 14.6.6 Limitations and Future Research

The present research is the first to study the intention, attitudes, beliefs and perceptions of two different groups of teachers regarding the use of drones in education in the context of aerial robotics. The results enrich the existing literature and open new avenues of research in aerial robotics and the use of drones in schools. Given that the research sample was convenient, the results of this study should be interpreted with caution. Future studies should investigate the aim and the objectives of this study with the use of a more representative sample which will consist of teachers of various subjects. Moreover, future studies should examine the aim and the objectives in a real-life learning environment where drones are used by both in-service teachers in their teaching and pre-service teachers within the context of their in-school practicum.

## References


Abarca, M., Saito, C., Cerna, J., Paredes, R., & Cuellar, F. (2017). *An interdisciplinary unmanned aerial vehicles course with practical applications* [Paper presentation]. IEEE Global Engineering Education Conference (EDUCON) 2017, Athens, Greece. https://doi.org/10.1109/educon.2017.7942856

Abutalipov, R., Bolgov, Y., & Senov, H. (2016). *Flowering plants pollination robotic system for greenhouses by means of nano copter (drone aircraft)* [Paper presentation]. IEEE Conference on Quality Management, Transport and Information Security, Information Technologies (IT&MQ&IS) 2016, Nalchik, Russia. https://doi.org/10.1109/itmqis.2016.7751907

Ahmad, M., Khordi Moodi, M., & Lohan, K. (2020). Social Robot for STEM Education. *Companion of the ACM/IEEE International Conference on Human-Robot Interaction* (pp. 90–92). ACM. https://doi.org/10.1145/3371382.3378291

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-t

Ajzen, I. (2020). The theory of planned behavior: Frequently asked questions. *Human Behavior and Emerging Technologies, 2*(4), 314–324. https://doi.org/10.1002/hbe2.195

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Prentice-Hall.

Alimisis, D. (2013). Educational Robotics: New challenges and trends. *Themes in Science and Technology Education, 6*(1), 63–71.

Allison, S., Bai, H., & Jayaraman, B. (2020). Wind estimation using quadcopter motion: A machine learning approach. *Aerospace Science and Technology, 98*, 105699. https://doi.org/10.1016/j.ast.2020.105699

Arís, N., & Orcos, L. (2019). Educational robotics in the stage of secondary education: Empirical study on motivation and STEM skills. *Education Sciences, 9*(2), 73. https://doi.org/10.3390/educsci9020073

Arnold, R., Yamaguchi, H., & Tanaka, T. (2018). Search and rescue with autonomous flying robots through behavior-based cooperative intelligence. *Journal of International Humanitarian Action, 3*(1). https://doi.org/10.1186/s41018-018-0045-4

Atmatzidou, S., Demetriadis, S., & Nika, P. (2017). How does the degree of guidance support students' metacognitive and problem-solving skills in educational robotics? *Journal of Science Education and Technology, 27*(1), 70–85. https://doi.org/10.1007/s10956-017-9709-x

Aydin, B. (2019). Public acceptance of drones: Knowledge, attitudes, and practice. *Technology in Society, 59*, 101180. https://doi.org/10.1016/j.techsoc.2019.101180

Bazelais, P., Doleck, T., & Lemay, D. (2017). Investigating the predictive power of TAM: A case study of CEGEP students' intentions to use online learning technologies. *Education and Information Technologies, 23*(1), 93–111. https://doi.org/10.1007/s10639-017-9587-0

Bermúdez, A., Casado, R., Fernández, G., Guijarro, M., & Olivas, P. (2019). Drone challenge: A platform for promoting programming and robotics skills in K-12 education. *International Journal of Advanced Robotic Systems*, *16*(1), 172988141882042.https://doi.org/10.1177/1729881418820425

Bertrand, S., Marzat, J., Maniu, C., Makarov, M., Filliat, D., & Manzanera, A. (2018). *DroMOOC: A massive open online course on drones and aerial multi robot systems* [Paper presentation]. IEEE International Conference on Control (CONTROL) 2018, Sheffield, United Kingdom. https://doi.org/10.1109/control.2018.8516765

Bogue, R. (2020). Humanoid robots from the past to the present. *Industrial Robot: The International Journal of Robotics Research and Application, 47*(4), 465–472. https://doi.org/10.1108/ir-05-2020-0088

Boon, M. A., Drijfhout, A. P., & Tesfamichael, S. (2017). Comparison of a fixed-wing and multi-rotor UAV for environmental mapping applications: A case study. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W6, pp. 47–54. https://doi.org/10.5194/isprs-archives-xlii-2-w6-47-2017

Byker, E., Putman, S., Handler, L., & Polly, D. (2017). Educational technology and student voice: Examining teacher candidates' perceptions. *World Journal on Educational Technology: Current Issues, 9*(3), 119–129.

Çalişkan, E. (2020). The effects of robotics programming on secondary school students' problem-solving skills. *World Journal on Educational Technology: Current Issues*, *12*(4), 217–230. https://doi.org/10.18844/wjet.v12i4.5143

Cañas, J., Martín-Martín, D., Arias, P., Vega, J., Roldán-Álvarez, D., García-Pérez, L., & Fernández-Conde, J. (2020). Open-source drone programming course for distance engineering education. *Electronics, 9*(12), 2163. https://doi.org/10.3390/electronics9122163

Carnahan, C., Crowley, K., Hummel, L. & Sheehy, L. (2016). New perspectives on education: drones in the classroom. In *Proceedings of Society for Information Technology & Teacher Education*, (pp.1920–1924). SI.TE.

Castro, E., Cecchi, F., Salvini, P., Valente, M., Buselli, E., Menichetti, L., Calvani, A., & Dario, P. (2018). Design and impact of a teacher training course, and attitude change concerning educational robotics. *International Journal of Social Robotics, 10*(5), 669–685. https://doi.org/10.1007/s12369-018-0475-6

Chen, C. J., Huang, Y. M., Chang, C. Y., & Liu, Y. C. (2019). *Exploring the learning effectiveness of "The STEAM education of flying and assembly of drone"* [Paper presentation]. IEEE Conference of Educational Innovation through Technology (EITT) 2019, Auckland, New Zealand. https://doi.org/10.1109/eitt.2018.00021

Chevalier, M., Riedo, F., & Mondada, F. (2016). Pedagogical uses of Thymio II: How do teachers perceive educational robots in formal education? *IEEE Robotics & Automation Magazine, 23*(2), 16–23. https://doi.org/10.1109/mra.2016.2535080

Chien, S. P., Wu, H. K., & Hsu, Y. S. (2014). An investigation of teachers' beliefs and their use of technology-based assessments. *Computers in Human Behavior, 31*, 198–210. https://doi.org/10.1016/j.chb.2013.10.037

Chiner, E., Gómez Puerta, M., & Mengual Andrés, S. (2019). Opportunities and hazards of the internet for students with intellectual disabilities: The views of pre-service and in-service teachers. *International Journal of Disability, Development and Education, 68*(4), 538–553. https://doi.org/10.1080/1034912x.2019.1696950

Chou, P. N. (2018). Smart technology for sustainable curriculum: Using drone to support young students' learning. *Sustainability, 10*(10), 3819. https://doi.org/10.3390/su10103819

Cliffe, A. D. (2019). Evaluating the introduction of unmanned aerial vehicles for teaching and learning in geoscience fieldwork education. *Journal of Geography in Higher Education, 43*(4), 582–598. https://doi.org/10.1080/03098265.2019.1655718

Custers, B. (2016). Drones here, there and everywhere introduction and overview. In *Information Technology and Law Series* (pp. 3–20). T.M.C. Asser Press. https://doi.org/10.1007/978-94-6265-132-6_1

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

Di Battista, S., Pivetti, M., Moro, M., & Menegatti, E. (2020). Teachers' opinions towards educational robotics for special needs students: An exploratory Italian study. *Robotics, 9*(3), 72. https://doi.org/10.3390/robotics9030072

DJI. (2021). *DJI for STEM education.* https://www.dji.com/uk/products/steam

DroneBlocks. (2021). *DroneBlocks: Using STEM and real-world drone applications.* https://www.droneblocks.io/

FAA. (2021). *Unmanned Aircraft Systems (UAS)*. https://www.faa.gov/uas/

Feron, E., & Johnson, E. N. (2008). Aerial Robotics. In *Springer Handbook of Robotics* (pp. 1009–1029). Springer. https://doi.org/10.1007/978-3-540-30301-5_45

Flybrix. (2021). *Flybrix drone, build, fly, crash rebuild*. https://flybrix.com/

Fridin, M., & Belokopytov, M. (2014). Acceptance of socially assistive humanoid robot by preschool and elementary school teachers. *Computers in Human Behavior, 33*, 23–31. https://doi.org/10.1016/j.chb.2013.12.016

Fullan, M. (2015). *The New Meaning of Educational Change* (5th ed.). Routledge. https://doi.org/10.4324/9780203986561

Fulton, M., Ahmed, M., & Sattar, J. (2019). *By land air, or sea: multi-domain robot communication via motion* [Paper presentation]. IEEE International Conference on Intelligent Robots and Systems (IROS) 2019, Macau, China.

Gaponov, I., & Razinkova, A. (2012). *Quadcopter design and implementation as a multidisciplinary engineering course* [Paper presentation]. IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE) 2012, Hong Kong, China. https://doi.org/10.1109/tale.2012.6360335

Gómez Ramirez, I., Valencia Arias, A., & Duque, L. (2019). Approach to m-learning acceptance among university students. *The International Review of Research in Open and Distributed Learning*, *20*(3). https://doi.org/10.19173/irrodl.v20i4.4061

Goodnough, K., Azam, S., & Wells, P. (2019). Adopting drone technology in STEM: An examination of elementary teachers' pedagogical content knowledge. *Canadian Journal of Science, Mathematics and Technology Education, 19*(4), 398–414. https://doi.org/10.1007/s42330-019-00060-y

Harris, A., & Jones, M. (2019). Teacher leadership and educational change. *School Leadership & Management, 39*(2), 123–126. https://doi.org/10.1080/13632434.2019.1574964

Jawad, A. M., Jawad, H. M., Nordin, R., Gharghan, S. K., Abdullah, N. F., & Abu-Alshaeer, M. J. (2019). Wireless power transfer with magnetic resonator coupling and sleep/active strategy for a drone charging station in smart agriculture. *IEEE Access, 7*, 139839–139851. https://doi.org/10.1109/access.2019.2943120

Jogezai, N., Baloch, F. A., & Khilji, G. K. (2021). School principals as change facilitators for ICT integration: Teachers' perspectives. *Psychology and Education Journal, 58*(5), 1016–1027.

Karydis, K., & Kumar, V. (2017). Energetics in robotic flight at small scales. *Interface Focus, 7*(1), 20160088. https://doi.org/10.1098/rsfs.2016.0088

Kennedy, J., Belpaem, T., & Lemaigna, S. (2016). *The cautious attitude of teachers towards social robots in schools* [Paper presentation]. IEEE International Conference on Robot and Human Interactive Communication (RO-MAN) 2016, New York, USA.

Khanlari, A. (2015). Teachers' perceptions of the benefits and the challenges of integrating educational robots into primary/elementary curricula. *European Journal of Engineering Education, 41*(3), 320–330. https://doi.org/10.1080/03043797.2015.1056106

Khanlari, A. (2019). The use of robotics for STEM education in primary schools: Teachers' perceptions. In *Smart Learning with Educational Robotics* (pp. 267–278). Springer. https://doi.org/10.1007/978-3-030-19913-5_11

Khanlari, A., & Mansourkiaie, F. (2015). *Using robotics for STEM education in primary/elementary schools: Teachers' perceptions* [Paper presentation]. 10th International Conference on Computer Science & Education (ICCSE) 2015, Cambridge, United Kingdom. https://doi.org/10.1109/iccse.2015.7250208

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education, 91*, 14–31. https://doi.org/10.1016/j.compedu.2015.08.005

Kim, H. S. (2013). Development of balloon-based autonomous airborne robot-kit. *The Journal of Korea Institute Electronic Communication Sciences, 8*(8), 1213–1218. https://doi.org/10.13067/JKIECS.2013.8.8.1213

Kim, S., & Lee, Y. (2016). The Effect of robot programming education on attitudes towards robots. *Indian Journal of Science and Technology*, *9*(24). https://doi.org/10.17485/ijst/2016/v9i24/96104
Knauder, H., & Koschmieder, C. (2019). Individualized student support in primary school teaching: A review of influencing factors using the theory of planned behavior (TPB). *Teaching and Teacher Education, 77*, 66–76. https://doi.org/10.1016/j.tate.2018.09.012
Kumar, V., & Michael, N. (2012). Opportunities and challenges with autonomous micro aerial vehicles. *The International Journal of Robotics Research, 31*(11), 1279–1291. https://doi.org/10.1177/0278364912455954
Liew, C. F., & Yairi, T. (2013). *Quadrotor or blimp? Noise and appearance considerations in designing social aerial robot* [Paper presentation]. ACM/IEEE International Conference on Human-Robot Interaction (HRI) 2013, Tokyo, Japan. https://doi.org/10.1109/hri.2013.6483562
Lupashin, S., Hehn, M., Mueller, M. W., Schoellig, A. P., Sherback, M., & D'Andrea, R. (2014). A platform for aerial robotics research and demonstration: The flying machine arena. *Mechatronics, 24*(1), 41–54. https://doi.org/10.1016/j.mechatronics.2013.11.006
Mahony, R., Beard, R. W., & Kumar, V. (2016). Modeling and control of aerial robots. In *Springer Handbook of Robotics* (pp. 1307–1334). Springer. https://doi.org/10.1007/978-3-319-32552-1_52
Makeblock. (2021). *Airblock STEAM drone, more than just an aircraft*. https://www.makeblock.com/steam-kits/airblock
Mei Wei, L., Yan Piaw, C., & Kannan, S. (2016). Relationship between principal technology leadership practices and teacher ICT competency. *Malaysian Online Journal of Educational Management*, *4*(3), 13–36. https://doi.org/10.22452/mojem.vol4no3.2
Nex, F., & Remondino, F. (2014). UAV for 3D mapping applications: A review. *Applied Geomatics, 6*(1), 1–15. https://doi.org/10.1007/s12518-013-0120-x
Ng, W., & Cheng, G. (2019). Integrating drone technology in STEM education: A case study to assess teachers' readiness and training needs. *Issues in Informing Science and Information Technology*, *16*, 061–070. https://doi.org/10.28945/4288
Niedzielski, T. (2018). Applications of unmanned aerial vehicles in geosciences: Introduction. *Pure and Applied Geophysics, 175*(9), 3141–3144. https://doi.org/10.1007/s00024-018-1992-9
Nonami, K., Hoshiba, K., Nakadai, K., Kumon, M., Okuno, H. G., Tanabe, Y., Yonezawa, K., Tokutake, H., Suzuki, S., Yamaguchi, K., Sunada, S., Takaki, T., Nakata, T., Noda, R., Liu, H., & Takadoro, S. (2019). Recent R&D technologies and future prospective of flying robot in tough robotics challenge. In *Tracts in Advanced Robotics* (pp. 77–142). Springer. https://doi.org/10.1007/978-3-030-05321-5_3
Nurdin, N., Inaku, D. F., Rasyid, A. R., Jalil, A. R., Alimuddin, A., Agus, M., & Al Azizi, S. Q. (2019). Participatory mapping and unmanned aerial vehicle (UAV) images for developing village level coastal geoinformation. *IOP Conference Series: Earth and Environmental Science, 370*, 012003. https://doi.org/10.1088/1755-1315/370/1/012003
Opoku, M. P., Cuskelly, M., Pedersen, S. J., & Rayner, C. S. (2020). Applying the theory of planned behavior in assessments of teachers' intentions towards practicing inclusive education: A scoping review. *European Journal of Special Needs Education, 36*(4), 577–592. https://doi.org/10.1080/08856257.2020.1779979
Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences, 11*(5), 204. https://doi.org/10.3390/educsci11050204
Papert, S. (1993). *The Children's Machine: Rethinking School in the Age of the Computer*. Basic Books.
Park, S., Her, J., Kim, J., & Lee, D. (2016). *Design, modelling and control of omni-directional aerial robot* [Paper presentation]. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2016, Daejeon, South Korea. https://doi.org/10.1109/iros.2016.7759254
Parrot. (2021). *Parrot for education*. https://edu.parrot.com/

Perrelet, A. (1970). The fine structure of the retina of the honey bee drone. *Zeitschrift for Zellforschung Und Mikroskopische Anatomie, 108*(4), 530–562. https://doi.org/10.1007/bf00339658

Pimthong, P., & Williams, J. (2018). Preservice teachers' understanding of STEM education. *Kasetsart Journal of Social Sciences, 4*(2), 289–295. https://doi.org/10.1016/j.kjss.2018.07.017

PytlikZillig, L. M., Duncan, B., Elbaum, S., & Detweiler, C. (2018). A drone by any other name: Purposes, end-user trustworthiness, and framing, but not terminology, affect public support for drones. *IEEE Technology and Society Magazine, 37*(1), 80–91. https://doi.org/10.1109/mts.2018.2795121

Reich-Stiebert, N., & Eyssel, F. (2016). Robots in the classroom: What teachers think about teaching and learning with education robots. In *Social Robotics* (pp. 671–680). Springer. https://doi.org/10.1007/978-3-319-47437-3_66

Rojas Viloria, D., Solan Charris, E. L., Muñoz Villamizar, A., & Montoya Torres, J. R. (2020). Unmanned aerial vehicles/drones in vehicle routing problems: A literature review. *International Transactions in Operational Research, 28*(4), 1626–1657. https://doi.org/10.1111/itor.12783

Rubio, F., Valero, F., & Llopis Albert, C. (2019). A review of mobile robots: Concepts, methods, theoretical framework, and applications. *International Journal of Advanced Robotic Systems, 16*(2), 172988141983959. https://doi.org/10.1177/1729881419839596

Sadaf, A., & Johnson, B. L. (2017). Teachers' beliefs about integrating digital literacy into classroom practice: An investigation based on the theory of planned behavior. *Journal of Digital Learning in Teacher Education, 33*(4), 129–137. https://doi.org/10.1080/21532974.2017.1347534

Sadaf, A., Newby, T. J., & Ertmer, P. A. (2012). Exploring pre-service teachers' beliefs about using web 2.0 technologies in K-12 classroom. *Computers & Education*, *59*(3), 937–945. https://doi.org/10.1016/j.compedu.2012.04.001

Saltan, F., & Arslan, K. (2017). A comparison of in-service and pre-service teachers' technological pedagogical content knowledge self-confidence. *Cogent Education, 4*(1), 1311501. https://doi.org/10.1080/2331186x.2017.1311501

Sampedro, C., Rodriguez Ramos, A., Bavle, H., Carrio, A., de la Puente, P., & Campoy, P. (2018). A fully autonomous aerial robot for search and rescue applications in indoor environments using learning-based techniques. *Journal of Intelligent & Robotic Systems, 95*(2), 601–627. https://doi.org/10.1007/s10846-018-0898-1

Santoso, F., Garratt, M. A., Anavatti, S. G., & Wang, J. (2021). Evolutionary aerial robotics: The human way of learning. In *Unmanned Aerial Systems* (pp. 1–23). Elsevier. https://doi.org/10.1016/b978-0-12-820276-0.00008-x

Scaradozzi, D., Cesaretti, L., Screpanti, L., Costa, D., Zingaretti, S., & Valzano, M. (2019). Innovative tools for teaching marine robotics, IOT and control strategies since the primary school. In *Smart Learning with Educational Robotics* (pp. 199–227). Springer. https://doi.org/10.1007/978-3-030-19913-5_8

Scherer, R., & Teo, T. (2019). Unpacking teachers' intentions to integrate technology: A meta-analysis. *Educational Research Review, 27*, 90–109. https://doi.org/10.1016/j.edurev.2019.03.001

Scherer, R., Siddiq, F., & Tondeur, J. (2019). The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Computers & Education, 128*, 13–35. https://doi.org/10.1016/j.compedu.2018.09.009

Schina, D., Valls Bautista, C., Borrull Riera, A., Usart, M., & Esteve González, V. (2021). An associational study: preschool teachers' acceptance and self-efficacy towards educational robotics in a pre-service teacher training program. *International Journal of Educational Technology in Higher Education*, *18*(1). https://doi.org/10.1186/s41239-021-00264-z

Selim, M. Y., & Kamal, A. E. (2018). Post-disaster 4G/5G network rehabilitation using drones: solving battery and backhaul issues. In *IEEE Globecom Workshops*. IEEE. https://doi.org/10.1109/glocomw.2018.8644135

Sisman, B., & Kucuk, S. (2019). An educational robotics course: Examination of educational potentials and pre-service teachers' experiences. *International Journal of Research in Education and Science, 5*(2), 510–531.

Smarkola, C. (2008). Developmentally responsive technology-literacy use in education: Are teachers helping students meet grade-level national technology standards? *Journal of Educational Computing Research, 38*(4), 387–409. https://doi.org/10.2190/ec.38.4.b

Staszowski, K., & Bers, M. (2005). *The effects of peer interactions on the development of technological fluency in an early-childhood, robotic learning environment* [Paper presentation]. American Society of Engineering Conference (ASEE) 2005, Oregon, USA. https://doi.org/10.18260/1-2--14380

Stolkin, R., Hotaling, L., Shery, R. P., & Sheppard, K. (2007). *A paradigm for vertically integrated curriculum innovation – how curricula were developed for school students using underwater robotics* [Paper presentation]. International Conference on Engineering Education (ICEE) 2007, Coimbra, Portugal.

Sungur-Gul, K., & Huseyin, A. (2021). Understanding pre-service teachers' mobile learning readiness using theory of planned behavior. *International Forum of Educational Technology & Society, 24*(2), 44–57.

Tang, H., Lin, Y., & Qian, Y. (2020). Understanding K-12 teachers' intention to adopt open educational resources: A mixed methods inquiry. *British Journal of Educational Technology, 51*(6), 2558–2572. https://doi.org/10.1111/bjet.12937

Teo, T. (2011). Factors influencing teachers' intention to use technology: Model development and test. *Computers & Education, 57*(4), 2432–2440. https://doi.org/10.1016/j.compedu.2011.06.008

Teo, T., & Lee, C. B. (2010). Explaining the intention to use technology among student teachers. *Campus-Wide Information Systems, 27*(2), 60–67. https://doi.org/10.1108/10650741011033035

Teo, T., Zhou, M., & Noyes, J. (2016). Teachers and technology: Development of an extended theory of planned behavior. *Educational Technology Research and Development, 64*(6), 1033–1052. https://doi.org/10.1007/s11423-016-9446-5

Tezza, D., Garcia, S., & Andujar, M. (2020). Let's learn! An initial guide on using drones to teach STEM for children. In *Learning and Collaboration Technologies. Human and Technology Ecosystems* (pp. 530–543). Springer. https://doi.org/10.1007/978-3-030-50506-6_36

Tilley, E., & Gray, J. (2017). Dronely. A visual block programming language for the control of drones. In *Proceedings of the SouthEast Conference* (pp. 208–211). ACM. https://doi.org/10.1145/3077286.3077307

Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I. M., & Yeo, S. H. (2016). A review on the use of robots in education and young children. *Educational Technology & Society, 19*(2), 148–163.

Tomić, T., & Haddadin, S. (2019). Towards interaction, disturbance and fault aware flying robot swarms. In *Springer Proceedings in Advanced Robotics* (pp. 183–198). Springer. https://doi.org/10.1007/978-3-030-28619-4_19

Tondeur, J., van Keer, H., van Braak, J., & Valcke, M. (2008). ICT integration in the classroom: Challenging the potential of a school policy. *Computers & Education, 51*(1), 212–223. https://doi.org/10.1016/j.compedu.2007.05.003

Tripolitsiotis, A., Prokas, N., Kyritsis, S., Dollas, A., Papaefstathiou, I., & Partsinevelos, P. (2017). Dronesourcing: A modular, expandable multi-sensor UAV platform for combined, real-time environmental monitoring. *International Journal of Remote Sensing, 38*(8–10), 2757–2770. https://doi.org/10.1080/01431161.2017.1287975

Vandeyar, S. (2017). The teacher as an agent of meaningful educational change. *Educational Sciences: Theory & Practice, 17*(2), 373–393. https://doi.org/10.12738/estp.2017.2.0314

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences, 39*(2), 273–315. https://doi.org/10.1111/j.1540-5915.2008.00192.x

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425. https://doi.org/10.2307/30036540

Vergouw, B., Nagel, H., Bondt, G., & Custers, B. (2016). Drone technology: Types, payloads, applications, frequency spectrum issues and future developments. In *Information Technology and Law Series* (pp. 21–45). T.M.C. Asser Press. https://doi.org/10.1007/978-94-6265-132-6_2

Watson, J. H., & Rockinson-Szapkiw, A. (2021). Predicting preservice teachers' intention to use technology-enabled learning. *Computers & Education, 168*, 104207. https://doi.org/10.1016/j.compedu.2021.104207

Weng, F., Yang, R. J., Ho, H. J., & Su, H. M. (2018). A TAM-based study of the attitude towards use intention of multimedia among schoolteachers. *Applied System Innovation, 1*(3), 36. https://doi.org/10.3390/asi1030036

Wu, D., Sun, X., & Ansari, N. (2020). An FSO-based drone charging system for emergency communications. *IEEE Transactions on Vehicular Technology, 69*(12), 16155–16162. https://doi.org/10.1109/tvt.2020.3043969

Zarafshan, P., Moosavian, S. A. A., & Bahrami, M. (2010). Comparative controller design of an aerial robot. *Aerospace Science and Technology, 14*(4), 276–282. https://doi.org/10.1016/j.ast.2010.01.001

Zeng, Y., Wu, Q., & Zhang, R. (2019). Accessing from the sky: A tutorial on UAV communications for 5G and beyond. *Proceedings of the IEEE, 107*(12), 2327–2375. https://doi.org/10.1109/jproc.2019.2952892

# Part IV
# Early Years Science Education

# Chapter 15
# The Influence of Grouping on Young Students' Learning While Coding: An Analysis of Talk in Different Pair Arrangements

**Garry Falloon**

**Abstract** In the past, studies have been undertaken investigating the effects of different student groupings on achievement and learning processes. Some studies have indicated benefits from ability group methods, while others trialling social and cooperative groupings have signalled benefits from self-select arrangements. However, very little recent work has been undertaken studying different student groupings in schools, and almost none involving young children. This article reports results from a study involving 45 six year olds, completing a series of coding challenges working in three different pairings. The study used an adaptation of Mercer's (J Computer-Assisted Learn 10:24–32, 1994) *Talk-Type* and Hennessy et al.'s (Learn Culture Social Interact 9:16–44, 2016) *Classroom Dialogue* analytical frameworks to evaluate the quality of oral discourse between the students, to determine any effect the different groupings had on learning progress and knowledge-building. Results suggested benefits from self-select methods, with students displaying higher levels of task engagement, relational trust and learning interdependence. These results are of high significance to early years' educators using grouping as a strategy to improve students' learning.

**Keywords** Grouping · Cooperative · Social · Learning · Students · Coding

## 15.1 Introduction

Student grouping is a common classroom pedagogical strategy used by teachers for differentiating instruction, increasing learning engagement, teaching students how to work together, and facilitating social interaction. Various grouping methods including ability, social, peer, selective and cooperative, have been investigated in the past to explore their efficacy for supporting learning in a range of different contexts. However, while student grouping is popular in schools, very little recent

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research investigating the 'learning performance' of different arrangements has been undertaken, and virtually none involving young students. This article reports methods and outcomes from a study investigating the learning of 45 six year olds organised in different pair arrangements, while completing a series of coding challenges using programmable robots and iPads.

The study applied a framework developed from Mercer's (1994) typology of talk types, supplemented by descriptors from Hennessy et al.'s (2016) SEDA classroom dialogue analysis tool, to determine any differences in student talk in each pairing, and to evaluate how this may have affected learning processes and knowledge development. Acknowledging the limitations of context and sample size, the more than 80 h of data collected over a 6 week period using a bespoke display and audio recording tool built into iPads, provided unique insights into how each arrangement differed in students' use of talk, and how this influenced their learning and rate of progress. It revealed interesting patterns in the use of Disputational, Cumulative and Exploratory talk across pair arrangements, that influenced the quality of interactions and subsequent learning progress. While more research is needed, the results suggest some pair arrangements may be more effective than others for delivering educational outcomes for young students. The study is particularly significant in the context of young children's coding and related computational thinking development, as earlier research suggests the nature and quality of talk interactions between children working in groups has a substantial influence over their ability to learn difficult concepts, solve learning problems, and engage in productive decision-making (e.g., Knight & Mercer, 2015; Mercer, 1994, 2008; Mercer & Littleton, 2007). Effective talk is instrumental in children's capacity to 'interthink'—that is, a process of *collective thinking* whereby "language is used for collective, creative problem solving" (Littleton & Mercer, 2013, p. 23). This capability is central to young children's ability to solve different problems involved in learning to code, and in more general learning tasks.

## 15.2 Research Questions

Data were collected responding to these questions:

1. What influence did organising students in social, similar achievement and different achievement pairs have on their use of different talk types when solving simple coding challenges?
2. To what extent were changes in student talk evident in each pairing, over the course of the study?
3. What influence did the use of different talk types have on knowledge-building?

## 15.3 Background

Research spanning many years has investigated different systems of classroom organisation, including student grouping methods. Studies as early as the 1930s explored interclass grouping and its effects on learning in specific subjects such as reading (e.g., Russell, 1946), and intraclass ability grouping for general instruction (e.g., Miller & Otto, 1930). In the 1950s, Floyd's (1954) Joplin Plan method held much promise for improving reading instruction, through its emphasis on 'vertical' grouping across class or grade levels, thereby minimising the negative stigma of within class grouping. Studies at the time pointed to the efficacy of this method for improved reading instruction, particularly when combined with differentiated curriculum, ongoing assessment and periodic regrouping (e.g., Morgan & Stucker, 1960).

However, recent questions have emerged about the capacity of homogenous ability grouping to offer teachers a platform for improving differentiated instruction. These concerns arise from implied assumptions that heterogeneity is minimal or non-existent in ability groups, and that "homogenous ability groups should attain their learning potential, regardless of the level of their group assignment" (Hallinan et al., 2003, p.121). More recent studies have also shown that within class ability grouping can potentially reinforce inequality and ethnic and social class segregation (Alpert & Bechar, 2008), and that their effectiveness relies heavily on teachers' awareness and preparedness to engage equitably in supporting the learning of all groups (Hallinan et al., 2003). Indeed, research exists indicating this is seldom the case, with evidence suggesting the quality and volume of instruction teachers provide differs according to the level of the group, with "instruction received by students in lower ability groups (being) inferior to instruction provided to children in higher ability groups" (Chorzempa & Graham, 2006, p. 529). Hallinan (2012) further suggests the comparatively better performance of capable students in ability groups can be attributed to stronger learner motivation, more teacher time allocated to instruction, and membership of a group where academic performance and achievement are encouraged.

Similar conclusions were determined from an interesting study by Cheung and Rudowicz (2003), who signalled the possibility that the effectiveness of ability grouping may vary according to the cultural context in which it is used. Their research surveyed nearly 3000 eighth and ninth graders and their teachers across 23 low, medium and high band Hong Kong schools, using multiple indicators (IQ, self-esteem, test anxiety, self-efficacy of study, examination results) to determine any influence ability grouping had on students' study behaviour and performance. Their results showed "no significant effect on students' self-esteem, academic self-concept and anxiety" (p. 250), but more notably, little effect on academic achievement. They suggested the relatively poor performance of ability grouping in this context may be attributable to the collective nature of Chinese culture that "emphasises teamwork, deference to the group, and perhaps authoritarianism or hierarchical orientation" (p. 251), and its emphasis on high achievement for *all* students. They speculate that these cultural norms may mitigate any negative influence from stigmatisation associated with ability grouping in Western cultures. Cheung and Rudowicz (2003) also identified the important social role groups played in their study by facilitating cooperation, friendship and positive integration amongst students of similar ability. They commented that cooperative and social learning "may be essentially the key to success in ability grouping" (p. 251), and vitally important for establishing interdependence between group members.

With the evolution of learning theory towards sociocultural orientations aligned with the work of Jerome Bruner and Lev Vygotsky, interest has turned to effective alternatives to within class ability grouping, based more on principles of cooperative and social learning. These arrangements can take different forms, but generally represent organisations that engage students of different or mixed abilities working together on structured or unstructured learning tasks. The premise underpinning cooperative grouping is that students should be associated in such a way that they realise tasks cannot be successfully completed unless they all succeed, and that doing so requires them to work collaboratively rather than competitively. However, Gillies (2004) points out that "just placing students in groups and expecting them to work together will not promote cooperation and learning" (p. 198), commenting that clear expectations must be communicated so students understand what is required of them, and how they are expected to work together and assist others to achieve learning goals. This perspective is supported by Kutnick et al. (2005), who differentiate between students working *in cooperative groups* and students working *collaboratively, in cooperative groups.* They signal dangers assuming students possess collaborative working skills (e.g., trust, support for others, respectful communication) when assigned tasks using cooperative grouping. Gillies (2004) highlights the importance of teaching students interpersonal and group skills including respectful communication, willingness to challenge and be challenged, and understanding the collective and democratic nature of cooperative decision-making, as the foundation to establishing mutual interdependence amongst group members. Under such conditions she argues group members are more inclined to contribute, as they perceive others consider their perspectives to be of value, and share concerns about the extent and quality of their learning.

Lou et al. (2000) identify the importance of learning task design to the effectiveness of student cooperative grouping. They comment that tasks need to promote positive interdependence as well as individual accountability, suggesting they should be structured so individual inputs "contribute positively to the accomplishments of others" (p. 102) in addition to achieving common goals. One way of facilitating this is assigning specific tasks or roles to group members, thus ensuring a level of individual accountability for personal performance and contribution. Furthermore, Gillies and Ashman (1998) argue that cooperative group tasks should be designed to require collaborative interaction between group members, rather than simply being a routine organisation or management method. They point to potential advantages of cooperative grouping for promoting discourse that supports more active student learning, through providing enhanced opportunities to use language for thinking, reasoning and decision-making. Slavin (2015) aligns this with cognitive perspectives supporting cooperative grouping, suggesting interactions between students support thinking development through enhanced information exchange and processing, in turn leading to greater conceptual understanding. He identifies cooperative grouping as ideal "opportunities for students to discuss, to argue, and to present and hear one another's viewpoints" (p. 11) which he states are important elements promoting student achievement.

However, Webb (2008) comments that while cooperative grouping may potentially provide effective venues for knowledge co-construction through Vygotskyian notions of peer scaffolding, their success hinges on the extent to which members are prepared to give and receive help and explanations, and provide time and support to others. She indicates the importance of explanations and interactions needing to be detailed, or as she terms, 'elaborate' in nature, rather than simply providing "an answer to a problem, without suggestions on how to solve it, or receiving no help at all" (p. 204). Successful cooperative groups rely on more than basic information transfer, requiring each member to be an active participant in the learning of the whole group by showing willingness to give and receive explanations and be corrected and challenged, and in turn, expect the same of others. Coordination amongst members of cooperative groups is crucial, and is facilitated by conversations where opinions and ideas "are acknowledged and discussed, not rejected or ignored (and) interaction is marked by a high degree of joint attention and respect" (Webb, 2008, p. 204). However, the early work of Bearison et al. (1986) also highlights the role cognitive conflict plays in knowledge construction, alerting to the fine line than must be negotiated between insufficient conflict—possibly indicating the suppression of alternative views, and too much conflict, which might discourage participants from asking questions or seeking information. Mercer's comprehensive analysis of classroom discourse over many years identifies the importance of student talk to critical but respectful knowledge-building, including the role of *Exploratory* talk in extending thinking, building new understandings, and solving problems (Mercer, 1994, 2004). In one of the few studies found investigating talk in digitally-supported learning, Knight and Mercer (2015), in reference to students' use of search engines in collaborative groups, concluded that "particular kinds of productive dialogue, notably exploratory talk, can be identified in and are related to effective collaborative information seeking" (p. 314). They associated this capability with improved learning performance, particularly when dialogue is encouraged that fosters sharing of information seeking strategies and supports critical discussion of the utility and accuracy of search results. While not specifically linked to computational thinking or coding—and the study was undertaken with older students, results do suggest that group arrangements are an important factor influencing learning success in digitally-focused tasks. Knight and Mercer (2015) position Exploratory talk as a cornerstone to knowledge-building, and suggest teachers need to teach students the skills, strategies and language needed to interact critically but respectfully in collaborative group arrangements.

Research into different approaches to forming cooperative groupings is scarce. Some early studies claim enhanced benefits from structured approaches to grouping (e.g., Gillies & Ashman, 1998), while others report advantages based on other considerations, including friendship, gender, age, class/stage, organisational ability, citizenship, and random assignment (e.g., Myers, 2012). Myers (2012) study was one of the few found that compared the effectiveness of socially-organised to randomly-assigned cooperative groups, by investigating the extent to which participants exercised organisational citizenship behaviours and how these impacted upon groups' decision-making and performance. Myers (2012) argues organisational citizenship improves cooperative group function, as it "contributes indirectly to the maintenance of the social and psychological structures of the workplace, that support the completion of tasks" (p. 51). He describes organisational citizenship as comprising three principal behaviours: helping (participants voluntarily help peers to prevent or solve problems); civic virtue (demonstrate commitment to the group by participating in governance processes), and sportsmanship (refrain from engaging in destructive or negative behaviour that would affect group performance). When participants display such behaviours, Myers claims commitment to the group and task is enhanced, relational satisfaction (trust of others and sense of purpose) increases, and communication improves. Myers study involved 126 students enrolled in a communications course, where the organisational citizenship behaviours of members of self-selected and randomly-assigned cooperative groups were compared, while completing an assignment. Results indicated that students in self-selected groups displayed higher task and group commitment, trust in other group members, and relational satisfaction. They also registered greater satisfaction with cognitive outcomes and affective elements of group work processes, and considered "they played a more active role in their work groups than students who are randomly assigned to their work groups" (Myers, 2012, p. 59). An earlier study by Chapman et al. (2006) found similar results, adding support to Myers conclusion that students who are able to choose with whom they work "generally work well together, and consider each other to be cooperative and indispensable" (2012, p. 62).

### *15.3.1 Student Talk in Cooperative Groups*

The prior review alerts to the role communication plays in promoting relational satisfaction, trust and task commitment, with some studies suggesting self-selected groups are more effective for establishing these. Moreover, there is a solid body of empirical evidence underpinning the contribution of student talk to problem solving and collaboration in cooperative groups. Studies spanning many years have highlighted the value of Exploratory talk in particular—that is, talk where "ideas are explicitly debated, requests for challenges are made, and alternative suggestions are offered" (Littleton et al., 2005, p. 5), for developing important cognitive and communicative capacities transferable beyond the immediate task (e.g., Dawes, 2004; Littleton et al., 2005). Littleton et al.'s intervention where young children (5–7 year olds) completed a series of 'Talk box' lessons designed to teach collaborative talk skills for working in cooperative groups, identified that children generated and implemented 'ground rules' for group talk, which fostered learning environments that were inclusive, positive and supportive. They described these as a "community of enquiry, enabling and encouraging the construction of personal meaning as well as shaping and confirming mutual understanding" (Littleton et al., 2005, p.19). Littleton and Mercer (2013) characterise talk interactions between members of such groups as enabling *Interthinking.* That is, talk not only serves sociocultural purposes associated with effective group establishment, but also as a means to facilitate *collective* thinking, combining the cognitive and creative talents of individuals "for teaching and learning, constructing knowledge, creating ideas, sharing understandings and tackling problems collaboratively" (Littleton & Mercer, 2013, p.32). They also point to the need for group talk to be *accountable*, where interactions seek evidence supporting perspectives, and actively demand further knowledge of relevance to the issue or problem. According to Resnick et al. (2018), *Accountable talk* is exploratory in nature, and is the basis for collective thinking and activity in cooperative groups. They identify three core elements of Accountable talk: accountability to knowledge (factual accuracy); accountability to reasoning (providing justification for perspectives), and accountability to community (respect for classmates' ideas). They comment that Accountable talk is developed over time and with practice, and is supported by teacher modelling and pedagogy that encourages understanding and adherence to 'ground rules' that allow equitable engagement opportunities for all students. Littleton, Mercer and colleagues point to close alignment between Accountable and Exploratory talk, with the former being an essential condition underpinning the latter and enhancing knowledge construction.

Although studies have consistently determined the value of Exploratory talk for supporting knowledge-building, problem solving and higher order thinking (e.g., Howe & Tolmie, 2003; Vass et al., 2014) they have equally determined major challenges to establishing this, and dangers assuming Exploratory talk is common between group members. Indeed, Mercer and colleagues' work analysing large volumes of classroom talk resulted in a typology of 'talk types', that variously described the characteristics of classroom talk as Disputational, Cumulative and Exploratory in nature (Knight & Mercer, 2015; Littleton et al., 2005; Mercer, 1994, 2000, 2004). Disputational talk is characterised by short exchanges reflecting disagreement or dispute between group members, resulting in individual decision-making and limited, separate, or disjointed action. Cumulative talk is more conciliatory, and tends to "construct a common knowledge by accumulation" (Mercer, 2004, p. 146). Cumulative talk is non-critical, lacking deeper engagement with, and critique of others' ideas and contributions. Discourse is typified by agreement, confirmation, reinforcement and affirmation, with limited interaction of a contesting nature. Exploratory talk is more productive dialogue where group members freely and constructively engage with others' thinking and ideas, seek explanations, offer alternatives, and actively participate in collective decision-making. While its establishment relies on high levels of relational trust and task commitment, research suggests Exploratory talk offers greater potential for knowledge-building and developing higher order thinking (Vass et al., 2014).

While considerable debate exists about the relative educational merits of ability, social and other group arrangements, literature is in general agreement about the important role communication plays in the 'learning performance' of groups of any type. Central to this is the influence of student talk in building collaboration, encouraging participation, and forming knowledge-building environments fostering the respectful exchange of ideas and perspectives. The following reports outcomes from a junior primary school study that applied an analytical framework developed from the work of Mercer (1994) and Hennessy et al. (2016), to analyse students' talk in a range of different pairings, while they were completing basic coding challenges using Blue-bots.[1] The aim of the study was to explore any influence the different arrangements had on students' knowledge-building, through analysis of the extent to which each stimulated the use of different talk types. It also investigated whether students' talk changed during the study period through spending more time working together in stable pairs, and if this impacted in any way on their collaboration.

## 15.4 Research Context and Student Organisation

Two year 1 classes comprising 45 six year olds and their teachers, Tristan and Sam (pseudonyms used throughout) from a small suburban multicultural public primary school in New South Wales (NSW), Australia, participated in the research. Data were collected during twice-weekly, up to 40 min sessions over a 6 week period in mid 2019. The classes comprised 24 boys and 21 girls, who were described by their teachers as being of "average to below average ability" (Tristan, interview, 18 June, 2019). Data collection occurred as students worked in pairs on coding challenges of varying complexity, using iPads, Blue-bots and shape and alphabet mats (Fig. 15.1). The challenges aligned with Early Stage 1 and Stage 1 objectives from the digital technologies strand of NSW K-6 Science and Technology syllabus (NESA, 2018) that focus on the computational skills of creating and following simple algorithms to solve problems, and understanding how instructions are used to control digital devices.

### *15.4.1 The Challenges*

Coding challenges were well suited to this study, due to the capacity of group or team coding tasks to generate talk and interaction through processes described by Brennan and Resnick (2012) as *Connecting* and *Questioning*. Through their research with Scratch, they noted "an individual Scratcher's creative practice benefited from having access to others through face-to-face interactions… (and) they were able to do more

[1] See https://www.tts-international.com/blue-bot-bluetooth-programmable-floor-robot/1015269.html.


**Fig. 15.1** One group using the iPad and a Blue-bot to code a letter challenge

than they could have on their own" (p. 10). This is supported by the earlier work of Mercer (1994) in the Spoken Language and New Technology (SLANT) project, who determined the "significance of communicative processes whereby computer-based activities are set up and carried out by children and their teachers as joint social action" (p. 25). He argued that collaborative computer-based tasks can "stimulate talk for learning" (p. 30), but that teachers need to pay close attention to class organisation—specifically reconsidering their use of disparate groupings, if the expectation is for students to work together on projects. He highlights "differences in skills and personal styles of working can overwhelm other aspects of the design of an activity" (p. 30), suggesting that explicit discursive strategies need to be taught to improve students' communicative awareness.

The tasks used university-supplied Blue-bots (small programmable floor robots) and iPads loaded with the Blue-bot app, and required students to construct and follow simple code sequences to navigate their device between shapes or letters laid out on plastic mats (Fig. 15.1). More advanced challenges required them to build and record sequences used to spell words, as illustrated in Challenge 5 (Fig. 15.2). The progressively more demanding nature of the challenges was a deliberate decision. It was considered doing this would provide students with more opportunity to engage in higher-level Exploratory talk, as they interacted to solve the increasingly more complex problems they were confronted with. Figure 15.2 contains one example from each of the first 6 challenges. In total there were 8 different challenges, with 8–10 tasks in each. Students programmed their device using the iPad Blue-bot app, entering their code using the screen interface and executing it remotely via Bluetooth connection. For all challenges, laminated task cards were provided to students, who used texture pens to record their code or sequence (Fig. 15.3). This study was the second involving students from this school, but the first with these classes.

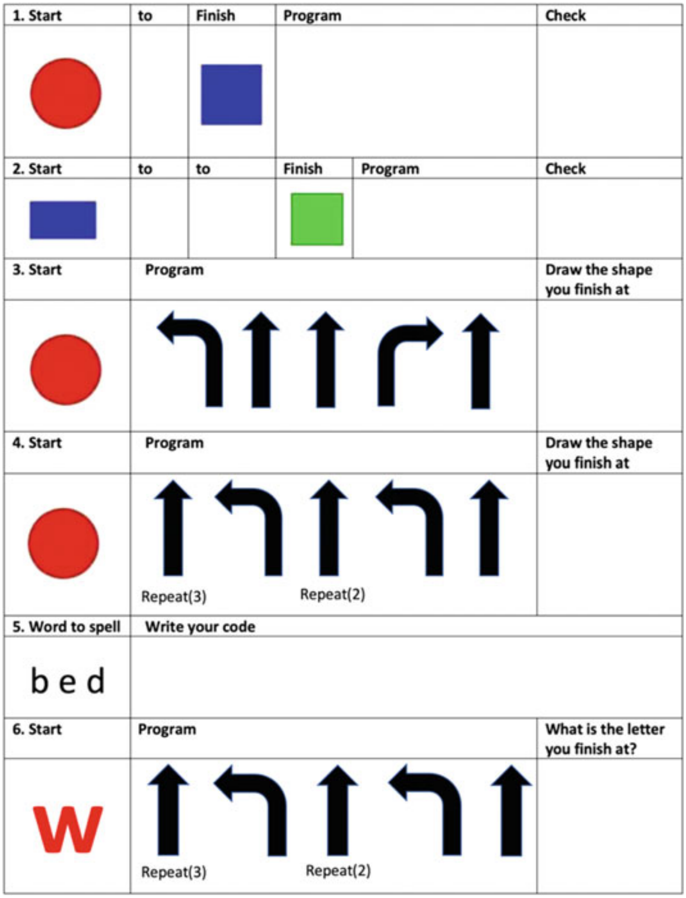


**Fig. 15.2** Examples from each of the first 6 coding challenges

### *15.4.2 Student Pairs*

Literature generally refers to grouping by 'ability'. However, as achievement data were used as the principal measure to determine pairings in this study, the term 'achievement' has been substituted, reflecting that "schools generally use measures of current performance, rather than measures of ability, to group students" (Evidence for Learning, 2019, p. 1). Therefore, after discussion between the researcher and the teachers regarding the desired profiles of pairs in each arrangement, students were organised by their teachers into:

**Arrangement 1**: Self-selected social pairs;
**Arrangement 2**: Similar achievement pairs;
**Arrangement 3**: Different achievement pairs.

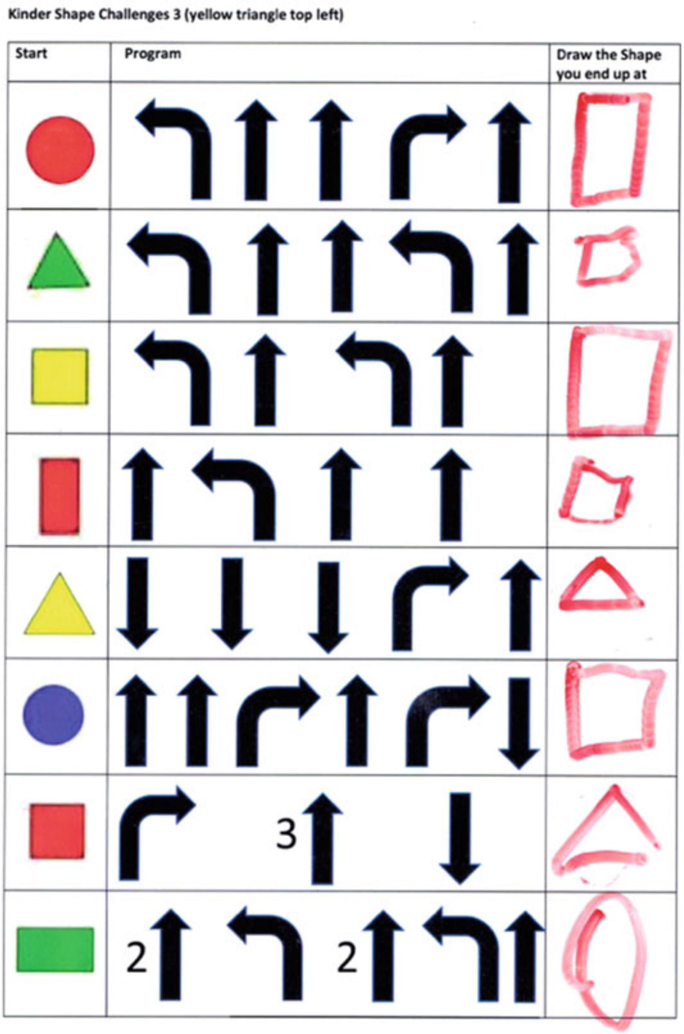


**Fig. 15.3** Students recorded their code on laminated cards

After introducing the topic, to form social pairs, both teachers randomly chose 4 students from each class and asked them to "choose a friend you would like to work with" (Tristan, personal communication, June 20, 2019). Eight pairs were formed, but due to absences during data collection, 6 were included in the analysis. Similar and different achievement pairs were teacher selected, based on achievement data from the Australian Council for Educational Research (ACER) Early Years Progressive Achievement tests (PAT) in numeracy and literacy. The PAT mathematics test assesses students' abilities in number, algebra, measurement, geometry and statistics, while the literacy test evaluates capabilities in print, vocabulary, reading comprehension, listening comprehension and phonics.

Table 15.1 provides general achievement profile information for each pair, summarising their percentile band and score difference for both tests. For some similar achievement pairs a score difference of less than 10 was used, as location within exactly the same percentile band was not possible (e.g., Sienna & Jac; Xavier & Noah). For different achievement pairs results fell beyond a 10 point difference, averaging 23.2 for mathematics and 14.8 for reading. Social pairs were mixed, although results for mathematics displayed greater average variation than reading (14.3 vs. 11.6).

The far right column of Table 15.1 contains short excerpts taken from teachers' comments recorded after pairs had been finalised. The teachers were asked to explain their pairing decisions based on the known characteristics of students, with particular reference to social relationships or friendships. Acknowledging the subjectively of these decisions, they do suggest teachers took into account the goal of the research and as much as possible paired different and similar achievement students to minimise social affects. With the possible exception of Zoe and Roy who were judged to "work OK together in maths" (Tristan, personal communication, June 21, 2019), students in similar and different achievement groups did not appear to be close friends. Teacher judgements were generally based on observations of students in the playground (who they liked to play with) and in the classroom (with whom they chose to collaborate), or known family or other associations. While it is recognised 'friendships' between students of this age can be transient and final pairs were ultimately decided using a combination of achievement results and teacher judgement, data does indicate a defensible level of fidelity between the results of these methods and the goals of the study. Notably, 10 students were deliberately excluded from selection as, according to the teachers, they could not be paired with sufficient accuracy. Such decisions provide confidence that the teachers understood the importance of careful pair selection. In total, continuous data were collected from 16 stable pairs over the 6 week period. These comprised 5 different achievement, 5 similar achievement, and 6 social pairs.

## 15.5 Methods

### *15.5.1 Data Collection and Sampling*

Data were collected using a display and audio recording system installed on each iPad. This system recorded all display and oral interactions as students worked on the challenges with the devices, and each other. The system had been used successfully in many previous studies (e.g., Falloon, 2016, 2017, 2019) and enabled the collection of highly authentic data, free from researcher contamination effects. In total, just over 86 h of recordings were captured during the 6 week period. However, due to the time-consuming nature of analysing video data and limited access to research

**Table 15.1** General achievement profile information for each pair

| Arrangement | Pair | Mathematics | | Reading | | Excerpt from teachers' comments |
|---|---|---|---|---|---|---|
| | | Percentile band | Score difference | Percentile band | Score difference | |
| Different | Thomas<br>Issie | 30–40<br>20–30 | 18 | 40–50<br>30–40 | 11 | They get along, but I wouldn't call them friends, really… they're both nice kids … usually get on with their work, yeah |
| Different | Trent<br>Harry | 60–70<br>40–50 | 24 | 60–70<br>50–60 | 13 | Pretty capable, really… but they both like to dominate… you know, be the boss… especially Harry, he can be bossy sometimes |
| Different | Aubitin<br>Jadon | 20–30<br>40–50 | 17 | 30–40<br>50–60 | 18 | Aubitin struggles a bit… he's really quiet. But they're good kids… helpful. They don't really play together at breaks, though… not that I've noticed, anyway… |
| Different | Isaac<br>Thomas | 30–40<br>50–60 | 21 | 30–40<br>40–50 | 12 | I think Thomas is the brightest… but fairly average, really. They're both… well, competitive. They play soccer on Saturday… but they're in different teams |
| Different | Adam<br>Vince | 70–80<br>30–40 | 36 | 70–80<br>40–50 | 20 | Well… Vince… um… he struggles… at everything. I think he's got problems at home… sometimes he brings them to school. Adam's a bright boy. I haven't had them working together before |
| Similar | Shanayd<br>Emily | 40–50<br>40–50 | 6 | 40–50<br>50–60 | 8 | They're both good kids… not startling ability though. I've noticed sometimes they play in groups with others in the oval… but I don't think they're great friends… not close, anyway |
| Similar | Susan<br>Hayden | 50–60<br>50–60 | 8 | 50–60<br>50–60 | 5 | Average… they'll work together if they have to but when they have a choice… I know Hayden likes to work with Bowie… |

(continued)

**Table 15.1** (continued)

| Arrangement | Pair | Mathematics | | Reading | | Excerpt from teachers' comments |
|---|---|---|---|---|---|---|
| | | Percentile band | Score difference | Percentile band | Score difference | |
| Similar | Xavier<br>Noah | 40–50<br>50–60 | 6 | 60–70<br>60–70 | 8 | They're in the same reading group… they get on OK. Not sure about friends… you can usually tell by who they play with in the oval, and I can't say I've noticed them playing together… |
| Similar | Sienna<br>Jac | 80–90<br>70–80 | 9 | 60–70<br>60–70 | 5 | Bright cookies… both in the top maths group. Sometimes I see them at play time when I'm on duty… but they're usually in different groups |
| Similar | Zoe<br>Roy | 60–70<br>60–70 | 5 | 50–60<br>60–70 | 6 | Both of them are good at maths… my group 1. Kind of similar in reading… they get on OK. They work together OK in maths… |
| Social | Bowie<br>Harrison | 40–50<br>20–30 | 18 | 50–60<br>30–40 | 14 | Harrison… he's below average… right across the board. Not sure if he's got some kind of learning disability… but he's got problems concentrating… almost ADHD. Bowie's a great kid… really popular… likes to help… |
| Social | Sharon<br>Sarah | 70–80<br>60–70 | 11 | 70–80<br>60–70 | 7 | Lovely kids… identical twins from Korea. They're so similar… but different… if you know what I mean… different personalities. But they do everything together |
| Social | Eric<br>Orina | 50–60<br>70–80 | 14 | 50–60<br>80–90 | 22 | Orina, she's is probably the brightest in the class. Good at maths… reading. Great family… really supportive. I think Eric and her went to [pre-school name] together |
| Social | Kyrie<br>Armaan | 60–70<br>60–70 | 9 | 60–70<br>60–70 | 6 | They get on well. Both really quiet kids. Just get on and do it. You know… it'd be good to have a class full of them… |

(continued)

**Table 15.1** (continued)

| Arrangement | Pair | Mathematics | | Reading | | Excerpt from teachers' comments |
|---|---|---|---|---|---|---|
| | | Percentile band | Score difference | Percentile band | Score difference | |
| Social | Andrew<br>Dean | 60–70<br>50–60 | 16 | 40–50<br>50–60 | 10 | Both good at sport. They love sport… competitive. I see them at break and they're always chasing around… running off energy… |
| Social | Sisillia<br>Collin | 30–40<br>50–60 | 18 | 50–60<br>60–70 | 11 | Collin's interesting. He's a shy kid… quiet… but quite capable, really. I'm surprised Sisillia wanted to work with him. She's kind of the opposite! |

support, a 50 h sample were selected for analysis. The sample were selected using these criteria:

1. Data were stable and continuous: the dataset was complete (i.e., from all challenges) and from the same students;
2. Approximately equal numbers of pairs were selected from each arrangement;
3. 'Codable' data were available: recordings were legible and the audio could be accurately transcribed;
4. Data were available for Challenges 1–7.

The duration of each recording ranged from 21 min 12 s to 41 min 18 s, and the average recording time was 25 min 19 s. Each recording was transcribed and time stamped. Sample data aligned with the analysis framework are provided in Appendix 1, while sections of coded transcripts from Challenge 5 for each pair type, are included in Appendices 2–4. The Appendices have been purposively collated to provide illustration of points raised in the Findings and Discussion. While the study comprised 8 challenges, the final challenge was an unstructured task where groups coded an original 'dance' for their Blue-bot. Data from this were not included in the final dataset.

### *15.5.2 Analysis Framework*

An analysis framework was developed from Mercer's general 'talk type' classifications supplemented by the work of Hennessy et al. (2016), whose study provided further elaboration on participant behaviours and talk characteristics that could be aligned with each type (Appendix 1). An additional classification (Other) was added to accommodate talk that was challenge-related, but wasn't *directly* applied to completing challenges. This included 'small talk' focused on resource or equipment organisation, understanding and defining challenges, seeking or giving help and direction from and to others, or talk that linked stages or parts of a challenge or provided feedback to workmates. 'Other' talk was important for establishing relationships between group members, and for planning and managing logistical aspects of groups' activities. Exploratory talk was defined as oral interactions that reflect respectful but critical engagement between students. These were characterised by genuine intent to support and further knowledge-building through questioning and challenging perspectives, accountability, negotiation and collective responsibility for decision-making. Exploratory talk is concomitant with '*Interthinking*', which Vass et al. (2014) describes as "how we use language for thinking together, for collectively making sense of experience and solving problems" (p. 63).

Cumulative talk was typically *cooperative talk*, characterised by uncritical sharing and exchange of existing personal knowledge, which gradually 'accumulated' to solve problems and complete tasks. Cumulative talk is affirming of others' perspectives, and while it is reasonably effective for 'getting the job done' it is less beneficial than Exploratory talk for new knowledge-building, through its primary focus on known information recall and exchange (Mercer, 1994). Disputational talk represents *divided thinking* that typically manifests in interactions of a conflicting nature, which, in this study, generally concentrated on access to resources, or seeking primacy for one's ideas, ways of working, or priorities. Disputational talk can be emotive in nature, often focusing on the individual and not the task. A predominance of Disputational talk can be unproductive and limit progress, as individuals seek dominance over others.

### *15.5.3 Data Coding and Analysis*

Altogether, 50 h (approx.) of sample recordings were coded against the 'talk characteristics' summarised in column 3 of the analysis framework (Appendix 1). The sample comprised data from each pair for 5 of the 7 challenges, including the first and last challenges. Before commencing, data aligned with each type were determined via negotiation between the researcher and assistant as substantial blocks or 'interactional strings' of talk, predominantly representing talk of a particular type. The lengthy coding process involved the researcher and assistant using the characteristics to identify blocks in data of each talk type. Working together, the researcher and assistant coded five transcribed recordings, during which discussions were held to generate common understandings of what each talk type 'looked like'. Talk type blocks were manually coded in Microsoft Word using different coloured highlighters (see Appendices 2–4), the start and stop times for each were also identified and time totals and percentages calculated. This was supplemented by combined review of each of the 5 display recordings, during which additional contextual information of relevance to coding decisions, such as preceding or subsequent actions, voice expression and tone etc., were logged.

Stage 2 involved the random selection of approximately 6 h of the 50 h data sample. Recordings were transcribed and independently blind coded, after which both reviewers met and coding decisions for each talk type were compared using inter-rater reliability measures. Kappa calculations were performed to determine the extent of agreement on data coded for each talk type. Following Gwet's (2012) guidelines, data upon which no agreement could be reached were discarded. Agreement calculations rated in Landis and Koch's (1977) 'moderate' and 'substantial' categories, with the smaller total number of agreements for Exploratory and Disputational talk contributing to their comparatively stronger results. Table 15.2 summarises the inter-rater agreement results.

The third stage involved the research assistant transcribing and coding the remaining 44 h of sample data, using the 'templates' developed in stage 2 as a guide. Although exceptionally time-consuming, doing this manually was important. While a technology solution could have been used, it would not have detected more nuanced cues that indicated not only *what* was said, but *how* it was said. This was particularly relevant for differentiating between Disputational and Other talk types,

**Table 15.2** Inter-rater agreement results for each talk type

| Talk type | Main characteristics | SE | CI (95%) | κ | Strength (Landis & Koch, 1977) |
|---|---|---|---|---|---|
| Exploratory | Collective<br>Negotiated<br>Accountable<br>Knowledge-building<br>Critically-constructive<br>Expansive<br>Reflective<br>Reciprocal<br>Evaluative | 0.066 | 0.546–0.803 | 0.675 | Substantial |
| Cumulative | Conciliatory<br>Information exchange<br>Non-critical engagement<br>Explanatory/clarifying<br>Non-expansive<br>Cyclic<br>Instructive<br>Repetitive<br>Agreeable | 0.033 | 0.527–0.657 | 0.592 | Moderate |
| Disputational | Conflicting<br>Personal/critical<br>Argumentative<br>Unproductive<br>Uncompromising<br>Emotive<br>Combative | 0.039 | 0.557–0.710 | 0.634 | Substantial |

(continued)

**Table 15.2** (continued)

| Talk type | Main characteristics | SE | CI (95%) | κ | Strength (Landis & Koch, 1977) |
|---|---|---|---|---|---|
| Other | Preparatory/planning<br>Organisational<br>Feedback<br>Transitional<br>Relational<br>Conversational<br>Communicative | 0.057 | 0.528–0.750 | 0.639 | Substantial |

| Percentage of recorded talk time by type, pair and challenge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group type | Pair | Challenge 1 | | | | Challenge 2 | | | | Challenge 3 | | | | Challenge 4 | | | | Challenge 5 | | | | Challenge 6 | | | | Challenge 7 | | | |
| | | D | C | E | O | D | C | E | O | D | C | E | O | D | C | E | O | D | C | E | O | D | C | E | O | D | C | E | O |
| Social | Andrew & Dean | 7 | 66 | 4 | 23 | 6 | 63 | 2 | 28 | | | | | 10 | 58 | 5 | 26 | 8 | 61 | 9 | 22 | | | | | 5 | 62 | 14 | 18 |
| Different Abilities | Trent & Harry | 37 | 55 | 1 | 8 | | | | | 36 | 52 | 1 | 11 | | | | | 32 | 53 | 0 | 15 | 24 | 60 | 3 | 13 | 30 | 57 | 2 | 10 |
| Different Abilities | Aubitin & Jadon | 39 | 40 | 1 | 20 | 37 | 50 | 1 | 12 | | | | | 34 | 47 | 3 | 15 | 31 | 48 | 2 | 18 | | | | | 35 | 46 | 2 | 16 |
| Social | Kyrie & Armaan | 11 | 55 | 7 | 27 | 13 | 52 | 9 | 25 | | | | | 9 | 59 | 7 | 24 | | | | | 5 | 63 | 11 | 20 | 7 | 60 | 11 | 22 |
| Similar abilities | Shanayd & Emily | 14 | 50 | 7 | 29 | 13 | 51 | 12 | 23 | 15 | 55 | 9 | 21 | | | | | | | | | 11 | 59 | 11 | 18 | 10 | 60 | 13 | 17 |
| Social (sisters) | Sharon & Sarah | 18 | 57 | 6 | 18 | | | | | 19 | 59 | 8 | 13 | | | | | 15 | 59 | 11 | 14 | 12 | 61 | 10 | 16 | 14 | 57 | 13 | 16 |
| Similar abilities | Susan & Hayden | 15 | 54 | 11 | 20 | | | | | 18 | 49 | 14 | 19 | 13 | 51 | 13 | 23 | 11 | 34 | 9 | 46 | | | | | 9 | 59 | 16 | 15 |
| Different Abilities | Thomas & Issie | 27 | 53 | 1 | 19 | 36 | 43 | 2 | 18 | 35 | 46 | 2 | 16 | 32 | 51 | 2 | 14 | | | | | | | | | 26 | 50 | 5 | 18 |
| Similar abilities | Xavier & Noah | 14 | 55 | 11 | 19 | 13 | 51 | 15 | 20 | | | | | 13 | 61 | 8 | 18 | 10 | 55 | 14 | 20 | | | | | 10 | 61 | 13 | 15 |
| Different Abilities | Isaac & Thomas | 22 | 56 | 2 | 20 | | | | | 30 | 59 | 3 | 8 | | | | | 35 | 44 | 1 | 21 | 23 | 64 | 3 | 10 | 29 | 55 | 3 | 13 |
| Different Abilities | Adam & Vince | 52 | 39 | 0 | 9 | 55 | 37 | 0 | 7 | | | | | 51 | 42 | 0 | 6 | | | | | 49 | 42 | 0 | 8 | 43 | 47 | 1 | 8 |
| Social | Bowie & Harrison | 7 | 64 | 15 | 13 | 4 | 58 | 24 | 13 | 6 | 59 | 25 | 10 | | | | | | | | | 8 | 49 | 19 | 23 | 6 | 54 | 18 | 21 |
| Similar abilities | Sienna & Zac | 19 | 53 | 10 | 18 | 17 | 49 | 13 | 20 | | | | | 13 | 52 | 17 | 18 | 15 | 51 | 14 | 20 | | | | | 11 | 56 | 12 | 20 |
| Social | Eric & Orina | 5 | 63 | 21 | 10 | | | | | 6 | 61 | 17 | 15 | 3 | 66 | 23 | 8 | 0 | 44 | 34 | 22 | | | | | 4 | 51 | 27 | 18 |
| Similar abilities | Zoe & Roy | 14 | 57 | 2 | 24 | 14 | 56 | 9 | 20 | 11 | 60 | 5 | 23 | | | | | | | | | 9 | 61 | 7 | 22 | 11 | 58 | 12 | 18 |
| Social | Sisillia & Collin | 13 | 58 | 8 | 20 | 10 | 59 | 12 | 18 | | | | | 9 | 64 | 11 | 15 | | | | | 9 | 62 | 10 | 18 | 8 | 61 | 11 | 19 |

**Fig. 15.4** Percentage of recorded talk time by type, pair and challenge

where expression, tone, inflection, emphasis and so on were important for determining an individual's *intent,* as communicated through their talk. Recognising this, during transcription, salient characteristics of talk were noted on transcripts where they provided additional cues indicating the speaker's intent. Examples can be seen in the use of bracketed adjectives and adverbs in Appendices 2–4. Doing this supported coding accuracy, although the subjective nature of assignment of adjectives and adverbs is acknowledged. The research assistant also noted the number of coded instances and total talk time, and from that calculated the percentage of coded talk for each talk type. This information was recorded at the end of each transcript, and the percentage totals entered into an Excel spreadsheet for further analysis (Fig. 15.4). The empty spreadsheet cells indicate data from the full set that were not included in the 50 h sample. The average percentage of talk type for each pair arrangement was calculated, as was the average percentage change in talk type across the challenges.

## 15.6 Results

Individual pair data were charted, as were data for the average percentage of each talk type for all pairs in the different arrangements. Beforehand, data were cleaned to remove outliers that would distort results. Because changes in talk type time were calculated as percentages between data points (i.e., intervals between challenges) and zero or very low baselines could result in changes of many hundreds of percent, it was decided to exclude data that exceeded 100% change between points. While this only applied to 6 instances, it minimised potential distortion effects from inclusion of these data. Figure 15.5 charts results for all pairs, while Fig. 15.6 charts the average percentage change in each talk type between data points for the different pair arrangements, calculated using the conventional formula (newvalue-oldvalue)/oldvalue.

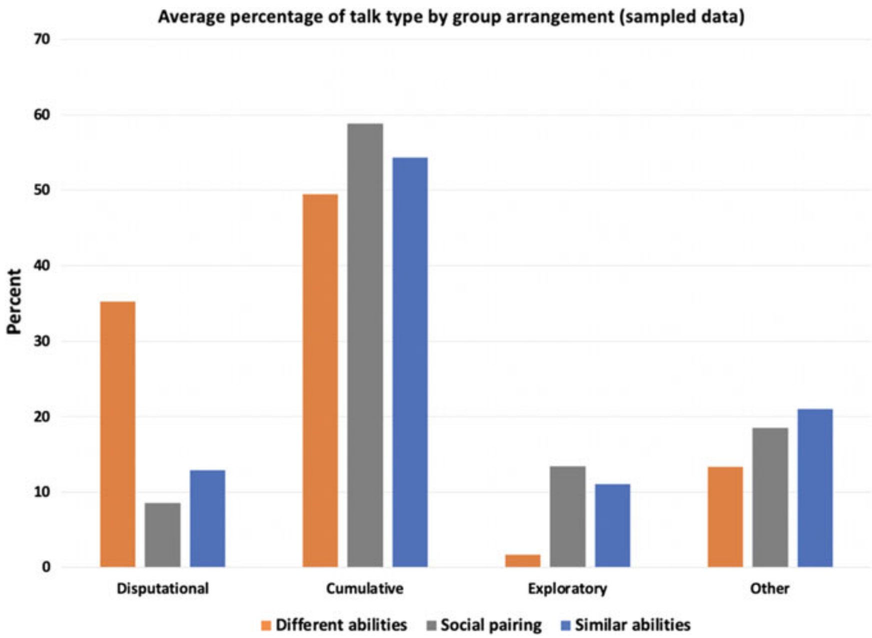


**Fig. 15.5** Average percentage of talk type by pair arrangement

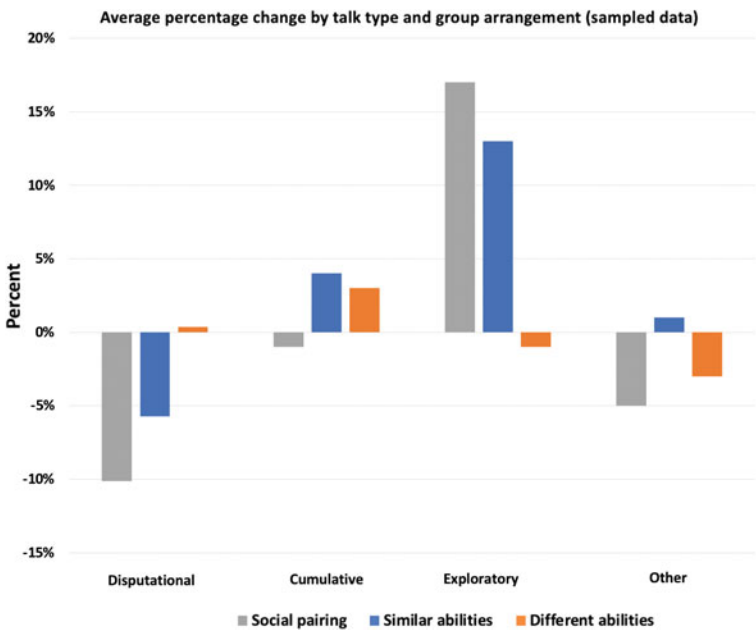


**Fig. 15.6** Average percentage change in talk type between data points, by pair arrangement

Results indicate students in social pairs exhibited the highest levels of productive, Exploratory talk, and the least unproductive, Disputational talk. While levels of Cumulative talk were comparable to similar achievement pairs, social pairs on average disagreed less, spent less time organising themselves, appeared more willing to support the learning of their workmate, and displayed greater collaboration. Data suggests the talk of social pairs was qualitatively different to that of other pairings, reflecting higher levels of relational trust, task commitment, and interdependence. This behaviour is illustrated in Appendix 2 where both students at different points assumed a respectful 'educative' stance towards the other, doing so with an apparent desire to correct a misconception or extend their workmate's knowledge (00:06:20–00:08:03). Although perhaps understandably given their age their exchanges lacked rigorous critique, a willingness to challenge and question their workmate's perspectives and ideas was still present (e.g., Appendix 2, 00:06:22). Also of note is that Eric and Orina, although self-selected, were at considerably different achievement levels (two bands separation). Despite this, data indicated they contributed equally to decision-making, respectfully acknowledging different perspectives, but also demonstrating willingness to challenge or offer alternative views where they identified potential mistakes, or could see an opportunity to support the other's learning (e.g., 00:13:21).

Over the 6 weeks of data collection, social pairs displayed the largest average percentage increase in Exploratory talk, while Other and Disputational talk exhibited the largest decrease. Cumulative talk remained reasonably stable, decreasing only slightly and remaining at a high baseline (57%). This result suggests social pairs became more relaxed and focused the longer they worked together—a conclusion supported by increased productive talk (more Exploratory, less Disputational), decreased organisational and 'small talk' (Other), and faster entry to challenges (e.g., Appendix 2, 00:00:05). Such behaviours were common for students in social pairs. They tended to spend less time negotiating 'ground rules' for working together (Littleton & Mercer, 2013), appearing to apply already-known relational practices and structures to their activities. They were also less confrontational, more reflective, and generally displayed higher levels of task commitment.

Students in similar achievement pairs exhibited comparable behaviours to social pairs, although they were slightly less willing to objectively evaluate and review their workmate's ideas, sometimes targeting their critique at the person and not the proposal (e.g., Appendix 3, 00:06:26). This manifested in more Disputational and marginally less Exploratory talk when compared with social pairs, and less improvement in both markers across data points. Analysis suggested students in similar achievement pairs took longer to get organised and start work, appearing to need to (re)negotiate work processes and structures (ground rules) more frequently than their socially-arranged classmates. Although this process was generally non-confrontational it did take longer, as illustrated by the average duration it took these pairs to complete challenges compared with social pairs (+4 min. 14 s). Appendix 3 illustrates this, with Susan and Hayden taking nearly 8 min to configure their device and negotiate who was going to use it first (00:00:44–00:07:54). Interestingly for these pairs, average Other talk actually increased slightly across data points, possibly suggesting initially-established ground rules may not have 'stuck' or weren't easily transferred. Again the example demonstrates this, with Susan and Hayden taking almost 2 min to decide who would use the iPad first, eventually resorting to 'paper-scissors-rock' to sort it out (Appendix 3, 00:06:39). Although Cumulative talk was similar to social pairs, higher average Disputation and Other talk and longer completion times, suggests similar achievement pairs may not have been as cohesive, and members were not as comfortable with challenging ideas or offering alternative perspectives. While similar achievement pairs 'got the job done', their practices appeared somewhat less effective for knowledge-building, with outcomes resulting from the 'accumulation' of existing understandings shared by both parties, rather than deeper exploration and revealing of new ones.

Finally, students arranged in different achievement pairs displayed the most Disputational and almost no Exploratory talk, on average spending over one third of their time arguing or debating access to or time with resources, seeking priority for their ideas over those of their workmate, or being personally critical of each other. Data indicated these students were more subjective and at times personal in their exchanges, and when issues couldn't be resolved – usually by one in some way achieving dominance over the other, they would often defer to authority (the teacher) to adjudicate (e.g., Appendix 4, 00:00:56–00:02:42). Of all arrangements, different achievement pairs took the longest to complete challenges, on average taking 3 min. 13 secs longer per challenge than similar achievement pairs, and 7 min 27 secs longer than social pairs. In four recordings, different achievement pairs failed to complete the challenges within the allocated lesson time. Perhaps unsurprisingly given their age and the novelty of using this technology, most Disputational talk resulted from competition for resources, and ended in failure to negotiate enduring work arrangements acceptable to both parties (e.g., Appendix 4, 00:01:5800:04:02). This reflected in interactional patterns of relatively brief task-progressing Cumulative talk, punctuated by equally brief Disputational talk, where the individual who was unsuccessful disputed the rights of their workmate or occasionally sabotaged their efforts (e.g., Appendix 4, 11.03–11.44).

Interestingly, different achievement pairs appeared more 'polarised' in their talk. This was demonstrated by lower levels of challenge-related 'small talk' - talk focused on clarifying or organising work arrangements, or planning how problems will be solved (Other). Talk was generally abrupt, comprising short sentences or statements switching between Cumulative and Disputational, with little else in between (e.g., Appendix 4, 00:09:50–00:18:03). Additionally, students in different achievement pairs, on average, displayed no qualitative improvement in their talk across data points. In fact, data suggests they actually got marginally worse (Fig. 15.6). In this study, students in different achievement pairs tended to operate as two individuals, rather than working as a collaborative or even cooperative unit. This often manifested in 'turn-taking' where one would hand over access to resources to the other, but not or only minimally engage with their efforts to solve the challenge (e.g., Appendix 4, 00:2:4200:04:02). In more extreme examples, one of the pair might attempt to disrupt or 'sabotage' the efforts of the other in order to gain control (e.g., Appendix

4: 00:05:18–00:06:16). Although such behaviours were comparatively rare, the ‘turn-taking’ characteristics of these pairs consumed much time, and their disconnected, competitive nature was fundamentally different to more collaborative and interactive ‘turn-taking’ processes adopted in the other arrangements.

## 15.7 Discussion

Responding to the primary question: *What influence did organising students in social, similar achievement and different achievement pairs have on their use of different talk types when solving simple coding challenges?* data clearly indicated that pairs used different ‘blends’ of talk while completing challenges, and that these strongly influenced the efficiency of their work and extent of knowledge-building, as evidenced by the greater or lesser presence of productive Exploratory, and unproductive, Disputational talk. However, analysis also indicated that while talk of a particular type may have been more prevalent in some pairings, it did not *exclusively* define the working characteristics of pairs. Deeper analysis of transcripts suggested students transitioned between talk types at different times, oscillating or moving between types responding to the immediate needs of a problem, when assisting the learning of their workmate, sharing strategies or knowledge, or in some cases, asserting or reasserting their ‘territory’.

Figure 15.7 presents a typology that conceptualises this process for these pairs, illustrating the ‘range’ of talk they used to solve challenges (Question 2). It maps the relationship between the prevalence of different talk types, their characteristics, and their influence on knowledge-building. By way of illustration, the sample pairs (Appendices 2–4) have been nominally positioned on the typology according to the range of talk displayed in their data, and its subsequent influence on knowledge-building ‘ways of working’ (Question 3). Towards the left are Adam and Vince, whose data indicated struggled to establish a solid base of ground rules from which to build agreed-to parameters supporting meaningful knowledge-building. The repeatedly Disputational nature of their talk demonstrated that any ground rules that were established were not enduring, and resulted from the attempts of one to overrule or dominate the other. Although from time to time talk transitioned to Cumulative enabling some progress to be made, this transition was temporary (e.g., Appendix 4, 00:04:02–00:06:37). The cycle of Disputational-Cumulative-Disputational and little Exploratory talk reflected less task commitment, trust and relational satisfaction, contributing to ‘divided thinking’ that inhibited knowledge-building. While Adam and Vince’s example was one of the more extreme, their interactions were, to a greater or lesser extent, not atypical of students in different achievement pairs. Members of these pairs frequently sought to establish their own *individual territory* through dominating resources, rather than sharing concern for efficiently and collaboratively working towards a common goal. Their talk resided in a relatively narrow range as indicated by the double-ended arrows on the typology. Their progress was

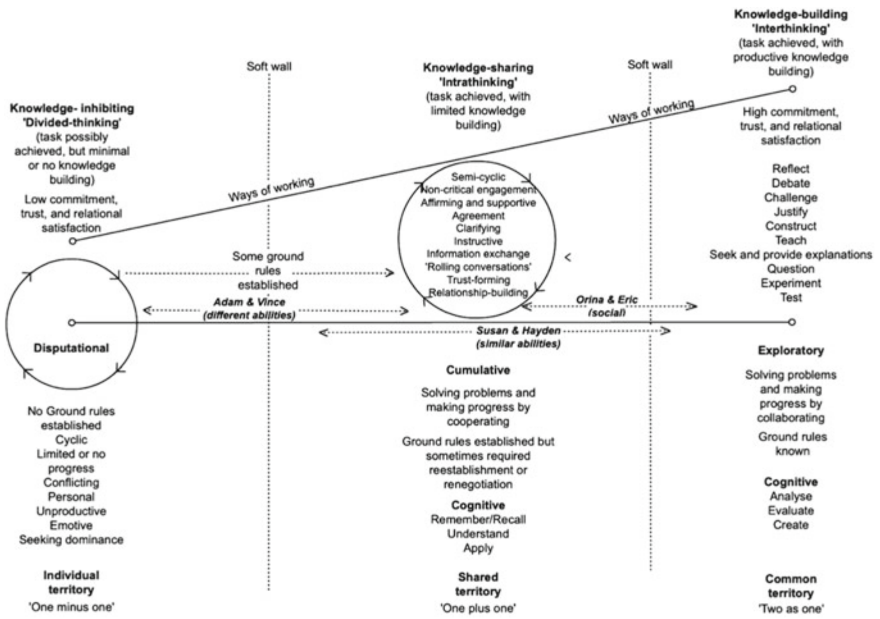


**Fig. 15.7** Pair locations on the typology of talk types: their characteristics and effects on knowledge building

intimately linked to whether ground rules, even temporary, could be established and adhered to.

Positioned towards the centre of the typology are students organised predominantly in similar achievement pairs. These are represented by data from Susan and Hayden (Appendix 3) and share a talk profile similar to those in social pairs, although with more Disputational and less Exploratory talk. Similar achievement pairs displayed the largest range of talk of all pairings, and also the highest average level of Other talk, which increased marginally across data points. In these pairs, talk coded as Other often aligned with more regular negotiation or renegotiation of working arrangements (ground rules), or engagement in unrelated 'small talk' (e.g., Appendix 3, 00:05:5500:07:54). Although students in these pairs experienced few problems establishing functional ground rules, they appeared to be more on a 'case-by-case' basis, periodically needing reestablishment or renegotiation. While interactions of students in these pairs were respectful and got the job done, they were generally less-challenging and less-expansive in nature. Challenges were completed through processes of information exchange, where one student formulated 'next steps' and communicated them to their workmate, rather than engagement in more collaborative processes of joint, negotiated formulation (e.g., Appendix 3, 00:07:55–00:10:22). This is described as *cooperative thinking* on the typology. Over time, knowledge of how to solve problems and complete challenges 'accumulated' through processes of information recall and application. While occasionally students in these pairs ventured into the more expansive realm of Exploratory talk, overall these forays were less frequent, and on average did not increase to the same extent as their social classmates (Fig. 15.6). Overall, talk suggested similar achievement students worked cooperatively rather than collaboratively, reflecting a willing *sharing of territory* through fair access to resources and reasonably equal opportunity to input into decisions.

Social pairs displayed the narrowest range of talk types. This pairing is represented on the typology by data from Eric and Orina (Appendix 2). Social pairs appeared to benefit from stable and transferable ground rules that supported collaboration and allowed them to get underway with their work quickly and efficiently, without the need for (re)negotiation within or between challenges. In this study, the friendship basis to social pairs appeared to transcend or nullify any possible effect of difference in achievement, with students showing higher and more stable levels of relational satisfaction, trust and task commitment. This reflected in less Disputational and the most Exploratory talk of all pairings. Social pairs also displayed the most improvement in talk (Exploratory) across data points, suggesting the more they worked together, the better they performed. On the typology social pairings are positioned towards the centre-right, more regularly penetrating the 'soft wall' between Cumulative and Exploratory talk than their similar achievement classmates. While data coded as Exploratory may not have been particularly critical in nature, it nonetheless reflected a tendency by these students towards greater cognitive engagement with the ideas and opinions of their workmate, and an emerging willingness not to accept what was said or being proposed, without challenge. However, what was different in social pairs was the constructive nature of these interactions, and how they were sometimes used as opportunities to teach or correct misconceptions (e.g., Appendix 2, 00:07:11–00:08:03). Very few examples were found in data suggesting students in social pairs interpreted questioning or being challenged negatively or personally. As indicated on the typology, students in social pairings generally operated in *common territory* where ideas were discussed, evaluated and implemented, if they were perceived as beneficial for achieving collective goals.

This behaviour aligns with Mercer's (2000) concept of *Interthinking*, which he describes as "joint, coordinated intellectual activity which people regularly accomplish using language" (p. 16). Although on evidence it would be difficult to claim that students in social pairs consistently functioned in that way, sufficient data indicates they adopted a more coordinated and collaborative approach than other pairings, at times displaying characteristics aligned with *Interthinking* through their use of language for "making connections with others in an attempt to build understanding, or to learn" (Pinnell & Jaggar, 2003, p. 901). This outcome is consistent with Myer's (2012) study involving university students, who showed higher levels of enduring relational satisfaction, trust and task commitment when working in self-selected peer groups.

The studies reviewed earlier involving older students and adults signalled the importance of social factors in establishing effective and productive groupings, whether these are organised according to achievement, or using other criteria (e.g., Cheung & Rudowicz, 2003; Gillies, 2004; Webb, 2008). Acknowledging limitations to this study (see later), these results tentatively suggest the same principle applies to younger students. Even accounting for the somewhat egocentric characteristics of children of this age, and the novelty effect of using this technology which could explain some of the behaviour of students in different achievement pairs, substantial differences still existed between the learning performance of students in these pairs and those in the other arrangements, particularly social pairs. The higher levels of Disputational talk in different achievement pairs had a substantial and negative influence on progress, and the extent to which interactions supportive of knowledge-building were possible. Furthermore, it appeared to gain some momentum the longer students worked together, unlike the other pairings where Disputational talk declined over time.

Kutnick et al. (2005) and Gillies (2004) highlight the importance of teaching students strategies and protocols to help them learn how to collaborate and work together more effectively in groups. These findings support that call, as no pairs in this study exhibited a 'perfect performance'. Indeed, like the earlier studies, results signalled dangers in making assumptions about if and how students learn in groups—or that just because students are arranged together, they will learn together. Clearly, this is not the case. However, what results do tentatively suggest is that some group configurations may offer more potential than others for establishing learning environments supportive of efficient and collaborative knowledge-building. However, while from a strict *efficiency* perspective this prospect holds considerable appeal, if used exclusively, such arrangements may not encourage students to learn how to work with others who are not their friends, or show tolerance and support for classmates with abilities different to their own. Doing this runs the risk of reinforcing social segregation—an historical criticism levelled at the use of homogenous groups (e.g., Alpert & Bechar, 2008). These wider purposes for students working in different groupings are important, and serve broader educational goals relating to citizenship, tolerance, respect for difference, and learning to live and work together. As pointed out by Myers (2012), we should consider carefully such outcomes as integral to decision-making about the use of different group arrangements.

### *15.7.1 Limitations and Conclusion*

Mercer's original 'talk types', supplemented by detailed behavioural and characteristic descriptors from Hennessy et al. (2016), provided a sufficiently fine-grained analysis framework to understand the dynamics of interactions between students, and note their effect on knowledge-building progress. However, despite considerable effort to promote validity through purposive sampling from a large dataset, blind coding and inter-rater agreement, it is acknowledged these measures only reduce and not eliminate the potential for alternative interpretations. If more resources were available, engagement of a third coder and inclusion of more data would have enhanced the trustworthiness of results.

Second, difficulties are noted that could limit the complete accuracy of pair categorisations. For example, while achievement data provided an objective statistical measure, teacher judgement was relied upon to determine existing social or friendship links for similar and different achievement pairs. While data suggests teachers took great care to ensure no or negligible overlaps with social pairs, the subjective nature of this process and the changeable nature of relationships between children of this age, is recognised. Finally, the defined context and relatively small number of participants limits the generalisability of this study's findings to other environments. Although definite patterns of talk and associated behaviours were apparent in pairs, it is possible that these classes, especially the students in different achievement pairings, were simply 'rogue' examples. The paucity of recent work on the effects of different groupings and the non-existence of studies into this involving young students, hampered evaluation of these results against studies of a similar nature. The absence of other recent work was surprising, given the popularity of grouping students as a regular classroom practice. Clearly much more work needs to be done in this area, not only to validate or challenge these results, but to reveal more up to date insights into the efficacy of this commonly-used pedagogical and classroom organisational strategy. Notwithstanding these limitations, it is hoped the analysis framework and innovative data methods used in this research, will provide an approach and impetus for other researchers to investigate the influence of different groupings with students using technology, and in different contexts. Little recent work appears to have been carried out in this area, and with increasing attention being paid to having students work in teams or groups in classrooms, it is time to rekindle research in this area.

## Appendix 1

**The Analysis Framework** (developed from Hennessy et al. 2016; Mercer, 1994)

| Talk type (from Mercer, 2004) | Participant behaviours (from Hennessy et al., 2016; Mercer, 1994) | Talk characteristics (used in coding) | Sample data |
|---|---|---|---|
| **Exploratory** ('interthinking', knowledge-building)<br><br>**Common territory** | Extends task<br>Critical but constructive engagement with others<br>Justifications sought, questions asked, alternative ideas offered<br>Different perspectives invited<br>Generates new ideas<br>Collaborative: work *as* a team<br>Pose questions<br>Challenge others<br>Seek new information or explanation | Accountable<br>Collective<br>Negotiated<br>Reasoned<br>Reflective<br>Metacognitive/higher order<br>Creative<br>Expansive<br>Reciprocal<br>Productive<br>Evaluative<br>Problem/task focused<br>Knowledge-building<br>Critically-constructive | E: Oh, I think I get it… I think we've missed a step… something's wrong… let's see… (pause)… let's go back… (pause)… three ups… turn that way (pause)… now 1, 2, this way… (pause)… ah… it's going the wrong way here…<br>O: Are you sure? (pause) let me see… um… yeah… you're… (pause)… we made it turn the wrong way… it had to go… ah… (pause)… left… it was left… not right… and we had it going right… *(social)*<br>B: I don't think that's right, Harrison… (pause)… I think we need to repeat 3, not 4… see…<br>H: But it has to go that way… um… that way and up…<br>B: Yes, but if you count, it'll go too far… (pause)…<br>H: Why?<br>B: See… (pause)… it's already going to be here… (pause)… 1… 2… and 3… so… see… it only has to go 3… |
| | | | H: Okay… thanks… (laughing)… it would have gone off the side…. *(social)*<br>H: Hey Susan (pause)… I wonder if we can do it easier? I wonder…<br>S: What?<br>H: (pause)… I wonder if there's a way to make it… (pause)… so we don't have to use so many arrows?<br>S: What d'ya mean?<br>H: Well… you know how we have to put lots of arrows in when it has to repeat numbers and stuff… (pause)… ah… it would be better if just used one… (pause)… but it could tell it to go two times… or three times… or something…<br>S: Like… put a number on the arrow?<br>H: Yeah… or something else… (pause)… so it does it lots… *(similar abilities)*<br>I: This one looks like the other one… it's the same pattern… (pause)… what do you think?<br>T: Can we just copy it?<br>I: That'll make it simpler…<br>T: Try it… (pause)… let's see what happens… *(different abilities)* |

(continued)

(continued)

| Talk type (from Mercer, 2004) | Participant behaviours (from Hennessy et al., 2016; Mercer, 1994) | Talk characteristics (used in coding) | Sample data |
| --- | --- | --- | --- |
| **Cumulative**<br>(cooperative thinking, common knowledge generated by 'accumulation')<br><br>**Shared territory** | Comments on nature and difficulty of task<br>Communicates procedures or instructions<br>Shares or seeks task-related information with other/s<br>Explains or clarifies task or problem for other/s<br>Seeks help if needed<br>Repeats others' ideas without critical review<br>Cooperative: work *in* a team<br>Works within what is already known<br>Shares resources and materials | Clarifying<br>Conciliatory<br>Cyclic<br>Confirming<br>Agreeable<br>Repetitive<br>Non-critical<br>Information exchange<br>Remember, recall, apply<br>Instructive<br>Non-expansive<br>Explanatory | H: Okay… okay… put forward one… now you've got to press… what?<br>T: Wait… I have to start again… (clears procedure)… okay… what is it?<br>H: Go 1 forwards… (pause)…<br>T: But where do we start? What's the letter, Harry?<br>H: Um… (long pause)… let me see… it's 'H'… ha-ha… 'H'… for Harry…<br>T: Okay… forwards 1… (adds code, pause)… now I've got to put… what?<br>H: Um… back 3… repeat 3 back…<br>T: Back… back… back… (adds code)… okay… (pause)…<br>H: Now turn right…<br>T: How many?<br>H: You only turn one time, Trent… it's not like forwards and stuff… *(different abilities)*<br>S: So, where does it go first?<br>E: 'W'… it has to begin on 'W'… and it's got to point up…<br>S: What?<br>E: Remember, Mr. Kim said it has to face to the top when it begins… (long pause)… |

(continued)

(continued)

| Talk type (from Mercer, 2004) | Participant behaviours (from Hennessy et al., 2016; Mercer, 1994) | Talk characteristics (used in coding) | Sample data |
|---|---|---|---|
| | | | S: 'W'… (pause)… it's down the bottom… (pause)…<br>E: Ready to go… umm… it needs to go forward 3 spaces… and then turn left…<br>S: Forward… ah… 1…2…3… (pause, adds code)… which way's left?<br>E: Over that way… (pause)… towards 'G'…<br>S: Okay… (adds code)…<br>E: Now… (pause)… you need to put 2 forwards again, and another left turn… then 1 forwards… so… (pause)… it's forward… forward… turn… forward… (pause)… *(similar abilities)*<br>V: 'D'… (pause)… what d'we do first?<br>A: What does it say?<br>V: Turn… (pause)…<br>A: Which way?<br>V: I dunno… (pause)… left… I think it's left… (pause)…<br>A: Okay… put it in… (pause)… it's that one…<br>V: Now what..? (adds code)…<br>A: Go 2 forwards…<br>V: Forward… forward… (enters code)…<br>A: And left again… (pause)… (V enters code)…<br>V: How much next?<br>A: It needs to go 3 more… 3 more forwards… (pause)…<br>V: 3… (enters 3 backwards)…<br>A: No… it's the other way, Vince… it's forwards, not backwards… (frustrated)… you put backwards… *(different abilities)*<br>A: We have to spell… ah… 'jump' (pause)… J-U-M-P… jump…<br>D: Where's 'J'?<br>A: It's up by the corner… there… (pause)…<br>D: Okay… so… we have to go to 'U'… so what's that?<br>A: Well… um… it's down there…<br>D: Long way… (pause)… so… if we turn… left…<br>A: Then go forward… ah… 1, 2, 3… 4… then… ah… (pause)…<br>D: It's left again… *(social)* |

(continued)

(continued)

| Talk type (from Mercer, 2004) | Participant behaviours (from Hennessy et al., 2016; Mercer, 1994) | Talk characteristics (used in coding) | Sample data |
|---|---|---|---|
| **Disputational** ('divided-thinking', knowledge inhibiting)<br><br>**Individual territory** | Won't share information<br>Personal decision-making<br>Targets the individual<br>Resources and materials accessed as individuals<br>Competitive<br>Ideas asserted, not shared or negotiated<br>Confrontational<br>Seeking primacy for one's perspectives<br>Undermines others<br>Individualised<br>Oppositional | Argumentative<br>Aggressive<br>Emotive<br>Personally/critical<br>Uncompromising/ non negotiable<br>Conflicting<br>Unproductive<br>Person-focused<br>Combative | V: You had it… (angrily)…<br>A: No I didn't… you got the last one… (pause)… you told me what to do…<br>V: Here! (abruptly)…<br>A: Why did you hide it, Vince..? That's stupid… (pause)…<br>V: It's my turn now… (angrily)…<br>A: You have to start on 'D'… (pause)…<br>V: No..! My turn… (enters code randomly)… and now 'Go'… (runs procedure)… haha… look at it… look… look… (laughing)…<br>A: Vince! (angrily, pause)… Mr. Kim… Mr. Kim… Vince's not doing what he's supposed to… Mr. Kim… (loudly, long pause)…<br>V: This is fun..! Crazy bug… (laughing)… *(different abilities)*<br>Z: I think we should do it together… (pause)… we could… like… ah… take turns…<br>R: But I'm better than you at the iPad…<br>Z: No… we need to take turns… I'm good the iPad too… (pause)…<br>R: You make mistakes… you don't know how to work it…<br>Z: Yes… I know how… (pause)… I've got one at home…<br>R: But this one's different… it's not the same… (pause)…<br>Z: Yes, it is… this one's just got a cover on it…<br>R: I'll go first… *(similar abilities)*<br>SH: Baby… you let me go first…<br>SA: But sis… you always go first… (pause)…<br>SH: I'm older than you…<br>SA: But…<br>SH: That's it… (pause)… you go next…<br>SA: It's not fair… *(social)* |

(continued)

(continued)

| Talk type (from Mercer, 2004) | Participant behaviours (from Hennessy et al., 2016; Mercer, 1994) | Talk characteristics (used in coding) | Sample data |
|---|---|---|---|
| **Other**<br>(link talk, social and small talk, negotiates ways of working, 'shapes' relationship/environment before task, within task, or after task) | Defining and understanding problems<br>Organising resources<br>Managing and understanding tasks<br>Building relationships<br>'Small talk'<br>Seeking and giving help<br>Establishing and/or (re)negotating ground rules and work organisation<br>Describing and sharing observations, learning, processes and procedures with other/s<br>Links stages or parts of a task<br>Reinforcing success/each other<br>Negotiating roles<br>Establishing interdependence | | V: You had it… (angrily)…<br>A: No I didn't… you got the last one… (pause)… you told me what to do…<br>V: Here! (abruptly)…<br>A: Why did you hide it, Vince..? That's stupid… (pause)…<br>V: It's my turn now… (angrily)…<br>A: You have to start on 'D'… (pause)…<br>V: No..! My turn… (enters code randomly)… and now 'Go'… (runs procedure)… haha… look at it… look… look… (laughing)…<br>A: Vince! (angrily, pause)… Mr. Kim… Mr. Kim… Vince's not doing what he's supposed to… Mr. Kim… (loudly, long pause)…<br>V: This is fun..! Crazy bug… (laughing)… *(different abilities)*<br>Z: I think we should do it together… (pause)… we could… like… ah… take turns…<br>R: But I'm better than you at the iPad…<br>Z: No… we need to take turns… I'm good the iPad too… (pause)…<br>R: You make mistakes… you don't know how to work it…<br>Z: Yes… I know how… (pause)… I've got one at home…<br>R: But this one's different… it's not the same… (pause)…<br>Z: Yes, it is… this one's just got a cover on it…<br>R: I'll go first… *(similar abilities)*<br>SH: Baby… you let me go first…<br>SA: But sis… you always go first… (pause)…<br>SH: I'm older than you…<br>SA: But…<br>SH: That's it… (pause)… you go next…<br>SA: It's not fair… *(social)* |

## Appendix 2

**Eric and Orina**: Social Challenge 5

| | |
|---|---|
| 00:00:05 | E: How about we take turns on the iPad, Olly?<br>O: Okay, so… okay, wait. Which one? You tell me what to press and I'll press it… let's go…<br>E: We have to start with 'W'… where's that? (pause)… 'W'?<br>O: It's down the bottom, Eric… by the 'X'… see… (long pause)…<br>E: So you need to touch 'Go' … this here… press the screen… no, wait… it's my turn… |
| 00:00:51 | O: Oh yeah… you go first on the iPad, and I'll go next…<br>E: Thanks Olly… it's good we share… (pause)… it says now we are doing okay…<br>O: Okay, so…<br>E: The system is so easy… this one… ah… it's easy<br>O: Okay… now which one?<br>E: Straight and go? (pause)…<br>O: You may so… go up 3 times… and then go… um… left… and then up 2 times and left, again…<br>E: So I have to put… (pause)… up 3… left… up 2… left… (adds code)… 'Go'… do I need to touch go? I'll show you something… (pause)… |
| 00:01:42 | O: We haven't finished yet… so… it needs to go forward… (EL adds code and runs procedure)…<br>E: It doesn't work… this doesn't work! When I press 'Go'… it doesn't go that way… why isn't it<br>working?<br>O: I think we need to clear it first…<br>E: … Yeah, but we did that! (long pause)… Oh, I think I get it… I think we've…<br>O: Are you sure? (pause) let me see… um… yeah… you're… (pause)… we made it turn the wrong way… it had to go… ah… (pause)… left… it was left… not right… and we had it going right… but we worked it out… and that's good Eric… okay. It's okay… okay, I know what to press now. So, 1, we just need one more up… |
| 00:03:51 | E: Up 1… (pause, adds code)… 'Go'… (runs procedure)… 'K'… write down 'K' on the sheet, Olly…<br>O: … Okay… this time where do we start? (pause)… 'D'…<br>E: Your go now…<br>O: 'D'… it's right here… (pause)… can you put it on 'D', Eric? (pause)…<br>E: Then we need to turn left and go 2 forwards… repeat 2 forwards… (pause, OL adds code)… then left again and repeat 3 forwards… (OL adds code)…<br>O: Okay… then 'Go'… (pause)… oopsie, that's a mistake… (long pause)… okay… 1… 2… 3… okay… 'Go'… (runs procedure)… what is it Eric?<br>E: It's landed on 'Q'… I'll put it on the sheet… |

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| 00:05:05 | O: You can go next, but I have to help you… okay (pause)… what? Okay… so it's your turn… so you have… so, you're going to go 2 of that… so put 2… (pause)… oh… where do we start? (pause)… it's on 'J'…<br>E: 'J'… good… 1… 2… down… and now… okay… now put that one… (pause, adds code)… now 'Go'… (pause)… no wait… wait… (pause)… got to go forwards 3… and *then* 'Go'… (pause)… Okay… we're done! (adds code, runs procedure) … we'll take turns… we'll go me, you, me, you. Oh my god, that's on… wait… yes, I got it… definitely 'Q'… (pause)… it's 'Q' again… can you write that down, Olly? (long pause)…<br>O: Okay… you can help me do the next one… we begin on 'S'… ah… where… oh… (pause)… here it is… (pause)… can you put it over there, Eric? (pause). Now… I'm going to do 1 down… and 1… right… (adds code)… and then 1… and then 1 up and then 1… 1 more… right. Does that sound okay to you?<br>E: But I don't think that's turn right…<br>O: Huh? |
| 00:06:29 | : 'Cos it has to turn left there … (pause)… yeah, left… left's that way…<br>O: No… ah… let's see… um… (pause) … down… turn… straight… (pause)… oh… I think you're right… it has to go that way… left… it's the other way (pause) … it's good you checked, Eric!<br>E: Mmm… left… otherwise it goes the wrong way… (pause)… you have to remember you're looking at it upside down, Olly… (pause)… that makes things go back to front…<br>O: Okay… (pause)… okay, so 1… and… turn… right… and go 1 straight… then… left… and then 2 more straight… repeat 2… 'Go'. Oh… I think I get it… no… I… are you sure?<br>E: Well… here, Olly… see… (pause)… here… turn around the other way so it's like the bot… (pause)…face the same way so you don't muddled up… and here, hold your hand up… (pause)… it's left… see it makes a 'L'… you can remember that way… (pause)… try it…<br>O: So if I… (pause)… let's see… ah… that makes it easier … I'll come over your side… (long pause)… right… 1… turn… 1… turn *left*… yes… *left*… and then up 2… then 'Go'… (pause, enters code, runs procedure)… |
| 00:08:06 | E: It's on 'O'… I'll write it… (pause)… and remember… we take turns on the iPad, Olly?<br>O: Okay, so… okay… wait. Which one? (pause)… I'll tell you what to put and you can put it… okay? (pause)… let's go…<br>E: So we need to press the 'X' first… this here… press the screen… we have to clear it (pause)… no… wait… it's my turn… (long pause)…<br>O: Oh yeah… you go now… and I'll go next…<br>E: It's good we share… (pause)… we're doing okay…<br>O: Okay, so… that's good… we must be doing it right…<br>E: The system is so easy… (pause)… this one… ah… it's easy… (pause)… what ya doing afterschool, Olly?<br>O: Mum's picking me up… I have to go to dance… (pause)… it's a bit boring sometimes… okay… now which one?<br>E: 'F'… turn and go… (long pause)…<br>O: You need to turn and go 3 forwards… |

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| 00:09:11 | E: Which way?<br>O: Um… right… right… it's sooo much easier over here… (pause)… then go up 3… and then go right… (pause)… and then up 3 again…<br>E: Wait… (pause)… right… 3… right… 3… (adds code)… so I have to touch 'Go'… and then… (pause)… ah… I'll show you something… (runs procedure)…<br>O: But it doesn't work! This doesn't work… (pause)… it doesn't go that way… (pause)…<br>E: Yes… yes… it's right… see… (pause)… turn… 3…. (pause)… turn again… 3… it's finished on 'X'… that's right… and I'll show you something<br>O: What?<br>E: You know before… I think if we make a mistake… we can just take one out… (pause)… we can just take it out… see… (removes code)… we don't have to do it all over again… we can fix it… we can fix the mistake!<br>O: That's easy! That makes it easier… a lot… (pause, removes code)… huh… it just disappears! I didn't know that… (pause)… thanks, Eric… so… can we do that all the time?<br>E: I think so… yeah… just pick it up and drop it… see …(pause, removes code)… we don't have to start again… |
| 00:11:43 | O: That'll save a lot of time, Eric…<br>E: …Okay then, your go…<br>O: What's the letter?<br>E: We have to start on 'P'… (pause)… it's over there… on the purple… it begins with 'P'…<br>O: Ha… ha… just like 'purple'… what'd we do first?<br>E: Repeat 2 forwards… (pause)… Hey, look Olly… it's the same… repeat 2 forwards… turn…repeat 2 forwards… turn…<br>O: It's the same as the last one… see… turn… 3… turn… 3… (pause)… only one more… (pause)… they're both got patterns! |
| 00:13:21 | E: Maybe we can just copy then… what we did last time?<br>O: Well… you have to count it, Eric… count how many… (pause)… and then… remember… use your hand to work out which way it has to go… how can you do that? (pause)… which way does it have to go… do you remember?<br>E: Okay… now… okay, so… you think 2 ups… and then go *that* way… turn… *right!* I get it now! And then… okay… and now straight… 2… good (long pause)…and… then turn… (pause)… right again… and up… wait…(pause)…<br>O: Up 3… it's up 3 at the end…<br>E: And then… 'Go'… 'Go' (adds code, runs procedure)…it's 'W'… (long pause)… that was a hard one, wasn't it Olly… I'm quite tired now… but we solved it… we've got good brains, eh! (pause)… okay, ready? You ready for the next one? (pause)… okay… your turn… so… where do we go? |
| 00:15:19 | O: Okay… we need to begin on 'H'… (long pause)… first we put 1 of those… put 1 up… (pause)… and then… back 3… 1… 2… 3… good… (adds code)…<br>E: … and now go… um… right… and up 2…<br>O: Okay… right… then 2… (adds code, but inserts left in error)…<br>E: Okay… now put left… and only 1 of those… only 1 this time… (pause)… good…<br>O: I just need to touch 'Go'… (pause, adds code, runs procedure)… |

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| 00:16:38 | E: What's the letter, Olly?<br>O: 'U'…<br>E: 'U'… good… we've finished… I'll write it down…<br>O: Mr. K… (loudly)… we've finished… (long pause)…<br>Mr. K: Good work you two! (pause)… let me see your sheet… (long pause)… ah… I think you might have made one mistake… the last one's not 'U'… (pause)… see if you can track down where the mistake is… (pause) |
| 00:21:03 | O: It's not 'U'… umm…<br>E: We need to check…<br>O: Okay… (pause)… shall we just start again, then?<br>E: No… I think we should just see if we can find the mistake… 'cos it would be better… (pause)…<br>O: Huh? |
| 00:22:15 | E: Remember… I showed you before… we can just change it really simple… you just pull it out… (pause)…<br>O: Oh, yeah… okay… (pause)… wait, I know! You do the iPad and I'll do the sheet…<br>E: What?<br>O: I'll read what the sheet says… and you see if it's right on the iPad…<br>E: Okay… (pause)…<br>O: Up 1…<br>E: Yep… |
| 00:23:21 | O: Repeat down 3…(pause)…<br>E: That's right… (pause)…<br>O : Then turn… um… what's this again? (pause)…<br>E: Let's see… that's… right… it's right… (long pause)… oh… I think… wait… yes - it should be right… we put left in here, and it should be right…<br>O : Where?<br>E: See… here… we put left, and see… (pause)… on the sheet… it says right…<br>O: I have to learn…<br>E: Okay… we can just change it… I'll take it out… (edits code)… okay… now 'Go'… (runs procedure)…<br>O: It's on 'O' now… I'll write it… |
| 00:25:26 | E: I think that's right… (pause)… good job, Olly! What d'we do now?<br>O: Yeah… great team… Eric! I'll go see Mr. Kim… |
| | Total coded talk time 25:26<br>Total coded events: 114<br>Duration and percentages of talk time (rounded)<br>Cumulative: 11:18 (43)<br>Disputational: 00:26 (2)<br>Exploratory: 08:37 (34)<br>Other (conversational/linking): 05:31 (22) |

## Appendix 3

**Susan and Hayden:** Similar achievement Challenge 5.

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|---|---|
| 00:00:44 | S: That one's a 'W'…<br>H: But we're on shapes…<br>S: Guys, we're not supposed to have it on shapes, are we? There should be heaps of letters… but we can't do it like this… (pause)…<br>H: Okay…we can just check…<br>S: Sometimes pencils have a wobbly bit that… (pause)…<br>H: What do we have to start at… start with… what is it Susan? |
| 00:01:36 | S: But, guys, the iPad is… why is our iPad like this, Mr K? Why is our iPad… Mr K, my iPad… my iPad… it's on shapes… it's on shapes…<br>H: Okay… go and tell Mr… I'm going…<br>S: It's on shapes… (long pause)…<br>H: Mr K, we need help… it's on shapes…<br>Mr. K: Oh… it needs to change to letters… we have to change the map…(pause)…<br>S: How d'we do that?<br>Mr. K: Okay… well, we have to touch this button here and change it to letters…(long pause)… can you see the letters map… (pause)… which one do we need? |
| 00:04:33 | S: This one… this is the right one…<br>Mr. K: Yes… now select it, and it'll change…<br>S: I see… it's easy… (pause)…<br>Mr. K Not hard at all… (pause)… are you fine now?<br>S: Yes… thank you… (long pause)…<br>H: Did you change it, Susan?<br>S: It's easy… see… all you have to do is touch here and change it on the list… (pause)… see? |
| 00:05:55 | H: Can I try? (long pause)… it's really easy… look at the other ones… there's lots of choice…<br>S: But we have to do our sheet… (pause)… okay… what do we do first, Hayden?<br>H: Who's going to use the iPad first?<br>S: I will… I went to Mr. K to fix the problem… so I should have first turn…(pause)…<br>H: But… (indignantly)… that shouldn't make a difference… we'll both get turns… (pause)… and any way… you can't remember… I saw the problem first (long pause)… maybe we should do paper<br>scissors…<br>S: Why?<br>H: So we can see who goes first!<br>S: Or…<br>H: Come on… three times… (pause)…<br>S: Okay… (long pause)… oh… good… it's me… how about I start? |
| 00:07:54 | S: Okay… (long pause)… oh… good… it's me… how about I start?<br>H: Alright… but it's my turn next… (pause)…<br>S: So, where does it go first?<br>H: 'W'… it has to begin on 'W'… and it's got to point up…<br>S: What?<br>H: Remember, Mr. K said it has to face to the top when it begins… (long pause)…<br>S: 'W'… (pause)… it's down the bottom… (pause)…<br>H: Ready to go… umm… it needs to go forward 3 spaces… and then turn left…<br>S: Forward… ah… 1…2…3… (pause, adds code)… which way's left? |

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| 00:08:49 | H: Over that way… (pause)… towards 'G'…<br>S: Okay… (adds code)…<br>H: Now… (pause)… you need to put 2 forwards again, and another left turn… then 1 forwards… so… (pause)… it's forward… forward… turn… forward… (pause)…<br>S: Forward… forward… turn… (long pause, adds code)… now…<br>H: That's finished… (pause)…<br>S: We have to press 'Go'… to make it… (runs procedure, long pause)… where did it go, Hayden?<br>H: It's on 'K'… I'll write 'K' on the sheet… (pause)… |
| 00:10:22 | S: Okay… what's the next one?<br>H: It's my turn now… you do the letters… (pause)… tell me what to put in…<br>S: 'D'… where's 'D' again?<br>H: Up the top… (pause)…<br>S: I've put it there… now… make it turn left… (pause)…<br>H: (adds code)… now… 2 forwards… (adds code, long pause)… hey Susan (pause)… I wonder if we can do it easier? I wonder… |
| 00:12:13 | S: What?<br>H: (pause)… I wonder if there's a way to make it… (pause)… so we don't have to use so many arrows?<br>S: What d'ya mean?<br>H: Well… you know how we have to put lots of arrows in when it has to repeat numbers and 8stuff… (pause)… ah… it would be better if just used one…(pause)… but it could tell it to go two times… or three times… or something…<br>S: Like… put a number on the arrow?<br>H: Yeah… or something else… (pause)… so it does it lots…<br>S: We'll do this one first… and then ask Mr. K…<br>H: It would save time… |
| 00:13:21 | S: You have to put a left turn… then 3 more forwards…<br>H: Left… (adds code)… (pause)…<br>S: Now press 'Go'… (runs procedure, pause)… put 'Q'… (pause)…<br>H: Right, now it's my go again… (pause)…<br>S: Hayden… do you like my hair?<br>H: Hair?<br>S: My mum says it's beautiful… (pause)… do you think it's beautiful?<br>H: But we have to do the next one! (insistently, pause)…<br>S: She puts this gel stuff in it before I come to school… (pause)… |
| 00:14:19 | H: Yes… what's the letter?<br>S: But… do you think it's beautiful, Hayden?<br>H: (angrily) Oh… yeah… yeah… but we need to do our work! (exasperated)…<br>S: I think it is… (pause)…<br>H: Let's… look… 'J'… um… 'J'… put it on 'J'… Susan… put it in 'J' … over there (insistently, long pause)… okay… now… back 2… (adds code)…<br>S: It smells so nice… and it's really soft… (pause)…<br>H: Now… turn left… and forwards 3… (pause)… 1…2…3… (pause)… |
| 00:15:31 | S: 'Go'… (HO runs procedure, long pause)… it's 'Q' again… that's 2 times… |

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| | Total coded talk time: 27:41<br>Total coded occurrences: 157<br>Duration and percentages of talk time (rounded)<br>Cumulative: 10:23 (38)<br>Disputational: 03:02 (11)<br>Exploratory: 02:55 (11)<br>Other (conversational/linking): 11:02 (39) |

## Appendix 4

**Vince and Adam**: Different achievement Challenge 5

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| 00:00:56 | V: I want to do it first…<br>A: No, you can't Vince… we have to take turns… (pause)… anyway… you don't know what to do…<br>V: I do so! Give it to me… (pause)… or I'll tell…<br>A: No! Mr. K… (pause)… Vince's being silly… Mr. K… (loudly, long pause)…<br>Mr. K: What's the problem here? (pause)… Vince… I hope you're being sensible and sharing? |
| 00:01:58 | V: But he won't let me have a turn… (angrily)…<br>A: He wanted to start… but he doesn't know how to do it… (pause)…<br>Mr. K: You have to take turns, okay… one can do the iPad, while the other does the Blu-bot… then you can swap over… (pause)… no arguments, okay…otherwise I'll take it off you…<br>A: I'll do the iPad first then… then you can do it… (pause)… you do the Blu-bot… put it on 'W'… we have to start on 'W'…<br>V: But I'm doing the next one… (insistently, pause)… |
| 00:02:42 | A: Right… (pause)… I need to go 3 forwards… (enters code)…<br>V: My turn…<br>A: No… you do the next one… the 'D' one… (long pause)…. then turn… which way… um… left… left… and 2 again… (enters code)…<br>V: Have you finished yet..? (abruptly)…<br>A: No… I've got two more… (sternly, pause)… why don't you help me…(pause)… we could do it<br>: together… you do the Blu-bot… then we can change…<br>V: But it's my turn..! (angrily)…<br>A: Why don't you read out the next one, Vince?<br>V: What? |

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| 00:04:02 | A: What's the next instruction? (long pause)…<br>V: Where are you up to?<br>A: It's here… um… 3 (pause)… turn… 2 ups… turn… (pause)… what's after the last turn?<br>V: One… it has to go 1 up… (pause)… then it's my turn on the iPad… okay… (abruptly)…<br>A: Up 1… (adds code)…now 'Go'… (long pause, runs procedure)… where does it finish, Vince?<br>V: Ah… it's here… what's the… (pause)…<br>A: That's 'K'… here… (pause)… what did you do with the sheet, Vince? |
| 00:05:26 | V: What sheet?<br>A: The one with the arrows on it… and the letters… (pause)… we have to write it in… (frustrated)…<br>V: You had it… (angrily)…<br>A: No I didn't… you got the last one… (pause)… you told me what to do…<br>V: Here! (abruptly)…<br>A: Why did you hide it, Vince..? That's stupid… (pause)…<br>V: It's my turn now… (angrily)… |
| 00:06:37 | A: You have to start on 'D'… (pause)…<br>V: No..! My turn… (enters code randomly)… and now 'Go'… (runs procedure)… haha… look at it… look… look… (laughing)…<br>A: Vince! (angrily, pause)… Mr. K… Mr. K… Vince's not doing what he's supposed to… Mr. K… (loudly, long pause)…<br>V: This is fun..! Crazy bug… (laughing)…<br>Mr. K: Vince..! (angrily)… where are you up to..? (pause)…<br>A: I've been trying… but Vince just keeps being silly..! (pause)…<br>Mr. K: This is your last chance, Vince… any more silliness and Adam can do it by himself… (pause)… and you can have time out… understand..! (authoritatively)…<br>V: Why did you have to tell? |
| 00:09:50 | A: 'Cos you're not doing what you're supposed to… you're being silly…(pause)… I'll put it on 'D'…<br>V: 'D'… (pause)… what d'we do first?<br>A: What does it say?<br>V: Turn… (pause)…<br>A: Which way?<br>V: I dunno… (pause)… left… I think it's left… (pause)…<br>A: Okay… put it in… (pause)… it's that one…<br>V: Now what..? (adds code)… |
| 00:10:31 | A: Go 2 forwards…<br>V: Forward… forward… (enters code)…<br>A: And left again… (pause)… (V enters code)…<br>V: How much next?<br>A: It needs to go 3 more… 3 more forwards… (pause)…<br>V: 3… (enters 3 backwards)…<br>A: No… it's the other way, Vince… it's forwards, not backwards…(frustrated)… you put backwards…<br>V: 'Go'..! (ignores, runs procedure)… |

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| 00:11:16 | A: Vince..! What are you doing..? (angrily)…<br>V: It's gone off… (laughing)…<br>A: Put it back, Vince… put… it… back! (very angry)…<br>V: It went on the carpet… *funny*… (long pause)… okay… I'll do it… where do we begin again?<br>A: On 'D'…<br>V: All right… I'll change it… (edits code, pause)…<br>A: Put *forwards* this time..! (insistently)…<br>V: How much? |
| 00:12:29 | A: 2…<br>V: Okay… forward… forward… (pause)… now what?<br>A: It needs to go left again… and up 3… (pause)…<br>V: Up… up… up… (pause)… now… 'Go'… (runs procedure)…<br>A: It's on 'Q'… (pause)… I'll write it on the sheet, Vince… (long pause)…<br>V: What's the next one..? (adds code, randomly)…<br>A: Don't do that, Vince..! Take it out… (pause)… take it out…<br>V: Where do we start? (abruptly)… |
| 00:14:11 | A: It's my turn with the iPad now, Vince… (pause)… *you* do the bug…(pause)…<br>V: Why?<br>A: 'Cos you did the last one… it's my turn now… (pause)… I'll get Mr. K…(pause)…<br>V: (pause)… all right… you do this one… and then I'll…<br>A: 'J'… where's J…J…J… (pause)… ah… over here…<br>V: I'll put it on… (pause)…<br>A: Okay… so what do we do first? |
| 00:15:40 | V: It has to go down… backwards 2 steps… repeat… (pause)…<br>A: Back 2…. (adds code)… let' see… where does that go to? (long pause)… 'T'…<br>V: How about we do one each? (pause)… you can do the first one… and I'll do one… and then you do one… (pause)…<br>A: But we're doing that now! (abruptly)…<br>V: No… I mean… I'll put in the next one… (pause)… the turn… and you can do the one after that… (pause)…<br>A: But that'll take too long..! We should just do one line each… (insistently)…<br>V: But… that's not fair! (complaining)… |
| 00:16:33 | A: Yes it is… you did the last one… and now I'm doing this one… (pause)…you can do the next one… (pause)… you just have to wait… (insistently, pause)… which way does it need to turn?<br>V: Left..! (abruptly)…<br>A: Left… (adds code)…<br>V: And then you need to go up 3 more… (pause)…<br>A: Then 'Go'… (adds code, runs procedure)…<br>V: It's on 'P'… it's landed on 'P'…<br>A: Let me look… (long pause)… um… I think it's 'Q'… not 'P'… 'P's the other way 'round… see… this is 'P'… (long pause)… I'll write it…<br>V: No… it's 'P'… (argumentatively, pause)… Mr. K (long pause)… |

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| 00:18:03 | Mr. K: What is it Vince?<br>V: Adam thinks it's 'Q'… and it's 'P'…<br>Mr. K: Which one?<br>V: Here… this one… it's 'P'… isn't it…<br>Mr. K: Actually… Vince… it is 'Q'… 'P's the other way around… (pause)… see… (pause)… this is 'P'…<br>V: Oh… I get confused… (pause)…<br>Mr. K: They look a bit the same, don't they..?<br>A: Yeah… and they're next to each other, too… (pause)… I'll put it on the sheet… (pause)…<br>V: Is it my turn now?<br>A: Yes… your turn to put it on the iPad… here… (pause)…<br>V: *My turn…* (abruptly)… |
| 00:21:13 | A: Okay… I know… (frustrated)… what's the first letter?<br>V: Um… 'S'… put it on 'S'… (long pause)…<br>A: Alright… backwards 1 space… then turn right… (pause)…<br>V: (adds code)… um… which way's right again?<br>A: That way… (pause)… it's that one, Vince… (pause)… then up 1…<br>V: (adds code)…<br>A: Now left… (pause)… the other way… and forwards 2 more… (pause)…<br>V: Forward… 1… 2… (adds code, pause)…<br>A: Now you need… 'Go'… (pause)… |
| 00:22:17 | V: 'Go'… (adds code, runs procedure)…<br>A: 'O'… it's on 'O'… can you put that on the sheet, Vince..? 'O'…<br>V: Where's the sheet?<br>A: Um… I had it… (pause)… it's somewhere… (pause)… where's it gone?<br>V: You're sitting on it… Adam… (long pause)… now it's all crunched up… (angrily)… oh… you should miss your turn… why did you sit on it, Adam?<br>A: I didn't mean to! (abruptly)…<br>V: I'll do the next one, then… (pause)…<br>A: No… it's my go… you had your go… (sternly)… |
| 00:23:33 | V: Put it on 'F'… it needs to go on 'F'… (pause)…<br>A: Can you put it there, Vince..? I can't reach… (pause)…<br>V: Where's?…<br>A: Over the other side… up near 'A'… (pause)…<br>V: 'F'… I see it… (pause)…<br>A: Right… what do we do first? Um… ah… (pause)… right… it has to turn right… (adds code)…<br>V: Now it has to go up… up… up… up… up… up… up…<br>A: What? |

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| 00:24:50 | V: Up… (pause)…<br>A: Forwards?<br>V: Yes… I said… up… up… up… up… up…<br>A: Argh…. how much?<br>V: That much! (long pause)…<br>A: Is it 3?<br>V: That's what I told…<br>A: No you didn't… you just said up… up… up… up… up…<br>V: 3<br>A: What now?<br>V: Um… (pause)… look… you need to do it again..! (pause)…<br>A: What d'ya mean? |
| 00:26:01 | V: See… just do same again… same as first one… (pause)…<br>A: Huh? (pause)… okay… (pause)… yeah… it's the same… makes it easy…(enters code)… now 'Go'… (runs procedure)…<br>V: 'X'… *I'll* put it on the sheet… (pause)…<br>A: Okay… thanks… (pause)… now it's your turn, Vince… (pause)…<br>V: Good… I like using the iPad… it's fun… (pause)… I like the controls…<br>A: I've put it on 'P'… it needs to start on 'P… (pause)… and then go forwards 2…<br>V: Forward… forward… (adds code, pause)… now… what's now?<br>A: Right… put in turn right… (pause)… |
| 00:27:13 | V: Turn… how much?<br>A: Just 1… you only need to turn right 1… (pause)… only 1… see (pause)…it's that way…<br>V: I know! (abruptly)… I'm not stupid… you're dumb… (adds code)…<br>A: You are… (abruptly)… go forwards 2… (V adds code)…. (pause)… and turn right… again…<br>V: Ha… it's like the last one… same… (pause)… (adds code)…<br>A: And go up 3… (V adds code)…<br>V: The end… 'Go'..! (long pause, runs procedure)… 'W'… (long pause)…<br>A: Okay… I do the last one… (pause)…<br>V: Can I help? |
| 00:28:26 | A: You tell me what to put… (pause)…<br>V: No… I mean, can I put it in the iPad… with you… um… you know… I do one and you do one… (pause)…<br>A: No! (insistently)… you had your turn… Vince… (pause)… anyway… why do you always have to have the iPad… why can't you be fair..?<br>V: I am fair… (pause)…<br>A: Where do we start? This is the last one… um… 'H'… (long pause)… forwards 1… then back 3… (adds code)…<br>V: How about..? (pause)… |
| 00:30:05 | A: Right turn… up 2… (pause, adds code)… then left… (pause)…<br>V: I'm going to play with it after this… make it…<br>A: Then 1… (pause)… 'Go'… (adds code, runs procedure)… 'O'… that's the last one… (long pause)… I'm going to show Mr. K… |
| 00:30:49 | V: Good… now I can play… |

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| | Total coded talk time: 30:49<br>Total coded exchanges: 168<br>Duration and percentages of talk time (rounded)<br>Cumulative: 17:56 (57)<br>Disputational: 09:25 (30)<br>Exploratory: 0 (0)<br>Other (conversational/linking): 04:00 (13) |

## References


Alpert, B., & Bechar, S. (2008). School organisational efforts in search for alternatives to ability grouping. *Teaching and Teacher Education, 24*, 1599–1612.

Bearison, D., Magzamen, S., & Filardo, E. (1986). Socio-conflict and cognitive growth in young children. *Merrill-Palmer Quarterly, 32*, 51–72.

Brennan, K., & Resnick, M. (2012). *New frameworks for studying and assessing the development of computational thinking* [Paper presentation]. American Education Research Association Annual Meeting, Vancouver, BC, Canada.

Chapman, K., Meuter, M., Toy, D., & Wright, L. (2006). Can't we pick our own groups? The influence of group selection methods on group dynamics and outcomes. *Journal of Management Education, 30*, 557–569.

Cheung, C., & Rudowicz, E. (2003). Academic outcomes of ability grouping among junior high school students in Hong Kong. *The Journal of Educational Research, 96*(4), 241–254.

Chorzempa, B., & Graham, S. (2006). Primary grade teachers' use of within-class ability grouping in reading. *Journal of Educational Psychology, 98*(3), 529–541.

Dawes, L. (2004). Talk and learning in classroom science. *International Journal of Science Education, 26*(6), 677–695.

Evidence for Learning. (2019). Within class achievement grouping: What is it? https://www.evidenceforlearning.org.au/the-toolkits/the-teaching-and-learning-toolkit/all-approaches/within-class-achievement-grouping/

Falloon, G.W. (2016). An analysis of young students' thinking when completing basic coding tasks using Scratch Jnr. on the iPad. *Journal of Computer-Assisted Learning, 32*(6). 576–593.

Falloon, G. W. (2017). Using apps to scaffold science learning in primary classrooms: Design, pedagogical and curriculum considerations. *Journal of Science Education and Technology, 26*, 613–628.

Falloon, G. W. (2019). Using simulations to teach young students science concepts: An Experiential Learning theoretical analysis. *Computers & Education, 135*, 138–159.

Floyd, C. (1954). Meeting children's reading needs in the middle grades: A preliminary report. *Elementary School Journal, 55*, 99–103.

Gillies, R. (2004). The effects of cooperative learning on junior high school students during small group learning. *Learning and Instruction, 14*, 197–213.

Gillies, R., & Ashman, A. (1998). Behavior and interactions of children in cooperative groups in lower and middle elementary classrooms. *Journal of Educational Psychology, 90*(4), 746–757.

Gwet, K. (2012). *Handbook of inter-rater reliability* (3rd ed.). Advanced Analytics.

Hallinan, M., Bottoms, E., Pallas, A., & Palla, A. (2003). Ability grouping and student learning. *Brookings Papers on Educational Policy, 6*, 95–140.

Hallinan, M. (2012). Effects of tracking and ability grouping on learning. In N. M. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 1098–1100). Springer.

Hennessy, S., Rojas-Drummond, S., Higham, R., Márquez, A., Maine, F., Ríos, R., García-Carrión, R., Torreblanca, O., & Barrera, M. (2016). Developing a coding scheme for analysing classroom dialogue across educational contexts. *Learning, Culture and Social Interaction, 9*, 16–44.
Howe, C., & Tolmie, A. (2003). Group work in primary school science: Discussion, consensus and guidance from experts. *International Journal of Educational Research, 39*, 51–72.
Knight, S., & Mercer, N. (2015). The role of exploratory talk in classroom search engine tasks. *Technology, Pedagogy and Education, 24*(3), 303–319.
Kutnick, P., Blatchford, P., & Baines, E. (2005). Grouping of pupils in secondary school classrooms: Possible links between pedagogy and learning. *Social Psychology of Education, 8*, 349–374.
Landis, J., & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*, 159–174.
Littleton, K., Mercer, N., Dawes, L., Wegerif, R., Rowe, D., & Sams, C. (2005). Talking and thinking together at Key Stage 1. *Early Years: an International Journal of Research and Development, 25*(2), 167–182.
Littleton, K., & Mercer, N. (2013). *Interthinking: Putting talk to work*. Routledge.
Lou, Y., Abrami, P., & Spence, J. (2000). Effects of within-class grouping on student achievement: An exploratory model. *The Journal of Educational Research, 94*(2), 101–112.
Mercer, N. (1994). The quality of talk in children's joint activity at the computer. *Journal of Computer-Assisted Learning, 10*, 24–32.
Mercer, N. (2000). *Words and Minds: How we use Language to Think Together*. Routledge.
Mercer, N. (2004). Sociocultural discourse analysis: Analysing classroom talk as a social mode of thinking. *Journal of Applied Linguistics, 1*, 137–168.
Miller, W., & Otto, H. (1930). Analysis of experimental studies in homogenous grouping. *Journal of Educational Research, 21*, 95–102.
Morgan, E., & Stucker, G. (1960). The Joplin Plan of reading vs a traditional method. *Journal of Educational Psychology, 51*, 69–73.
Myers, S. (2012). Students' perceptions of classroom group work as a function of group member selection. *Communication Teacher, 26*(1), 50–64.
New South Wales Education Standards Authority (NESA). (2018). *The Science and Technology K-6 Syllabus*. NESA publications.
Pinnell, G., & Jaggar, A. (2003). Oral language: Speaking and listening in elementary classrooms. In J. Flood, D. Lapp, J. Squire, & J. Jensen (Eds.), *Handbook of research on teaching the english language arts* (2nd ed., pp. 881–913). Lawrence Erlbaum.
Resnick, L., Asterhan, C., & Clarke, S. (2018). *Accountable talk: Instructional dialogue that builds the mind.* UNESCO: International Academy of Education (Belgium) & International Bureau of Education (Switzerland). https://www.researchgate.net/publication/324830361_Accountable_Talk_Instructional_dialogue_that_builds_the_mind
Russell, D. (1946). Inter-class grouping for reading instruction in intermediate grades. *Journal of Educational Research, 39*, 462–470.
Slavin, R. (2015). Cooperative learning in elementary schools. *Education 3–13, 43*(1), 5–14.
Vass, E., Littleton, K., Jones, A., & Miell, D. (2014). The affectively constituted dimensions of creative Interthinking. *International Journal of Educational Research, 66*, 63–77.
Webb, N. (2008). Learning in small groups. In T.L. Good (Ed.), *21st Century Education: A Reference Handbook* (pp. 203–211). Los Angeles, CA: Sage.

# Chapter 16
# Messing with Maltesers and Magnets: Toward a Theorization About Affordances Using Tablet Technology in Inquiry Teaching and Learning

**Deb McGregor, Sarah Frodsham, and James Bird**

**Abstract** This chapter is focused on discussion about the ways that tablet technology can support teaching and learning in inquiry contexts within STEM. The discussion about the nature of inquiry teaching and learning with digital technology is drawn from a series of case lessons in elementary science within the topic of 'Properties of Materials' in the UK. The research project informing this chapter examined teacher, young learners and non-participant observer's perspectives of the same events, namely two sequential science lessons one with and the other with-out the use of tablet technology. A socio-cultural perspective of learning was adopted. Reflections on these three contrasting viewpoints of the processes of teaching and learning informs a theorisation about practice that utilises digital technology. As Clarke and Svanaes (Tech knowledge for schools. An updated literature review on the use of tablets in education, 2014), Geer et al. (Br J Educ Technol 48:490–498, 2017) and more recently the OECD (Digital strategies in education across OECD countries, 2020) report, there is still no 'clear line' about which devices best support education, or indeed, how digital devices can be most effectively used. This chapter, therefore, offers suggestions about the ways that affordances or opportunities for young learners should be noted and pedagogically promoted more effectively in science inquiry situations.

**Keywords** Tablet technology · Ipads · Affordance · Science · Inquiry

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## 16.1 Introduction

Only within the latter half of the last decade has the use of tablet technology become a widely used resource for teaching and learning (Chou & Block, 2018; Maich & Hall, 2016) science. Despite the significant investment by Government, schools, colleges, however, there appears not to have been a commensurate theorisation of the ways it could be used for educative purposes. McFarlane (2019), in her relatively recent report, evidences how there is no guarantee that where technology is made available it necessarily impacts positively on learning. There also remains the challenge not only of embedding the use of digital technology (DfE, 2019) across settings to ensure teachers consistently support learners to effectively develop digital literacy (OECD, 2020), but also recognising what exactly teachers should pay attention to pedagogically to enrich and enhance inquiry learning. To effectively utilise different digital technologies requires different pedagogical strategies (Falloon & Khoo, 2014). For example, a stand-alone PC for each group of five pupils, or one laptop per child or one tablet per pair of students requires alternate teaching strategies to support effective learning. This chapter considers, therefore, empirical data drawn from studies of young students working in boy-girl pairings using tablets to suggest what an effective pedagogical approach to adopt is. Although the context of inquiry might seem very specific, there are findings that emerge that can be applied across STEM lessons utilising any form of digital technology. In investigating how the teacher and young students interacted with the technology to resolve learning tasks the juxtaposed understandings about how it can be used became apparent. This chapter therefore considers how, within the context of inquiry science, teachers and young students perceive and utilise the affordances that tablet technology can provide to augment learning. Interestingly, teacher's perceptions, learner's understandings and non-participant observer's views of the ways that digital technology can be used for learning do not entirely coincide. This presents a range of pedagogical implications.

Studies which focus on the affordances offered by tablet technology, such as the iPad, within specific disciplines suggest that there is an increase in cognitive, emotional and general engagement. For example, a teacher and teaching assistants, working with pupils aged 4–5, reported how it helped young learners understand key concepts and improved their communication, listening and fine motor skills within their numeracy and literacy lessons (Clarke & Abbott, 2016). Interestingly, young learners also intuitively appeared to have understood the purpose of the apps employed and how to navigate them (ibid.). Additionally, apps can easily incorporate a range of multimodal communication tools to augment researching information, recording an investigation, capturing data, reporting on findings and generating a report on an inquiry. There are, however, reportedly over 500,000 apps available for teachers to choose from for a typical tablet. This only serves to exacerbate the issue of pedagogical decision-making about the best way to utilise technology in learning. However, within science education key iPad apps, such as Explain Everything (EE) are freely available and widely used. In the study reported on here, this flexible application allows teachers to invite their young learners to look at previously saved pictures, text and audio files, as well as provide a way of them [the children] archiving their own work in a range of visual, textual, audio and even videoed formats. The hardware of the iPad, and the EE software, as described in this chapter offer many different opportunities, or affordances for both teaching and learning. The ways that the iPad and EE were utilised, and extended affordances (Gibson, 1977; Gomes et al., 2014) for teaching and learning about materials and their properties within a series of science lessons was the context of the study reported on here.

## 16.2 Affordances, Inquiry and Theoretical Framing of the Study

This paper draws on an ecological perspective of affordances (Gibson, 1977, p. 67) that reflects "metaphorically" the features or elements of a learning environment that comprises the classroom for learners and influences the processes they engage in. Just like particular habitats (like those in a classroom) have different places or niches for learning [like for example, a mobile trolley holding laptops, digital sensors or probes that can be used for datalogging or a specific corner providing pre-loaded reading on tablets] that offer quite different opportunities or affordances for learners [i.e.: digital probes monitoring environmental changes in temperature or reading text conveying important scientific information]. Having these different kinds of resources available influences the nature of activity and discussion that learners engage in. Considering contrasting materials such as a small A4 sized whiteboard and a dry wipe pen or an interactive whiteboard commanding half a classroom wall that responds to the contact of human digit provide contrasting media and physical space for an individual or whole class to relate to. When, for example, one learner is quietly working on sketching a diagram of their experimental approach or a whole class is collectively contributing to a tabular results table to provide an overview of many iterations of an investigation the processes of learning initiated are quite different. That is the affordances made available to learners differ. On the one hand the individual sketcher is focused solely on representing the equipment as accurately as possible within an A4 space, drawing with a coloured pen. The activity, thinking and discussion required for such will contrast starkly with the rest of the class collating and entering their data onto large sized spreadsheet. Learners interacting with each other through the medium of one tabular representation of the data collected by a whole class will require discussion, negotiation, decision-making and even metaphoric navigation to locate the correct cells for each data entry. Therefore, we are considering not only physical factors but also human interactions that affect or influence learning with tablets. This therefore resonates with the ecological view that multiple factors or elements, of both a physical and biological nature affect the way beings behave. The tablets [photographic facility, word-processing options, audio recording etc.], the materials [maltesers, water, sand, salt, cups, spoons, etc.] each contribute and interactions [of both actional and verbal nature] each in different ways conjure a classroom habitat that provides the environment within which the learning activity takes place. These multiple features, then, can be 'seen' or assumed to offer more or different forms of affordance to students depending upon the learning to be achieved.

Falloon & Khoo (2014) introduces the way tablet technology, in the guise of iPads, was widely thought to be a 'game changer' (Geist, 2011, p. 1, cited in Falloon & Khoo (2014) because it was a portable and a mobile device that could 'radically enhance student learning, by enabling them to collaborate and access information from anywhere at any time' (Falloon & Khoo, 2014, p. 1). However, the most effective ways to adopt iPads (for example, for individual, small group or whole class activity; rotate sets around the school or provide dedicated devices for particular rooms) that maximises benefits for learning are yet to be clarified (McFarlane, 2019). Technology, however, is recognised to offer a range of affordances (Gaver, 1991) that can be utilised by both the teacher (Drennan & Moll, 2018) and learners (Falloon & Khoo, 2014) in differing ways.

Adopting a socio-cultural perspective (Edwards, 2000) of classroom activity that embraces the ecological perspective of affordances and values the interactions between teacher and students, appreciates the context within which they are working, attempts to make sense of meaning-making and takes account of cultural histories (Robbins, 2003) is what we pay attention to. The focus of our research being concerned with ways that tablet technology extended affordances to enhance the quality of inquiry learning within the context of 'Properties of Materials'. In adopting a socio-cultural lens we were keen to consider the ways that the teacher and students interacted both with each other and the tablet technology and how peers worked collaboratively to resolve their scientific queries. Consequently, consideration of the ways that the technology supported and mediated learning processes, through the affordances it offered was key. Just as Norman (1999) distinguishes between 'real' and 'perceived' affordances, we recognised too, for example, that a digital screen allows the 'real' affordance of touching [or haptic experience]. Touch-screen enabled technology [a physical feature of the screen which allows the software environment to be controlled by touching] is adopted by tablet technology. The ways that touching in different forms [swiping, pressing, sliding for example] can then be considered as a 'perceived' affordance that tablet technology offers. Besides physical or 'real' affordances we also consider those that are 'hidden' [that is students working out what to do collectively to activate different facilities available on the tablet] may not so obvious, but these can be related and influential in STEM learning.

Through this series of lessons we offer illustrative episodes that present various ways that affordances of the technology and each other, as humans, were made available for learning. Through observation and discussion we were able to discern how the use of tablets was embedded within the socio-cultural practice that emerged within the particular science classroom episodes. We also consider how both the teacher and the students understood the nature of affordances that materialised for them during their joint participation in the scientific inquiries and through post-lesson discussions.

### *16.2.1 Adopting an Ecological Perspective of Affordances*

We adopted an ecological perspective of affordances (Gibson, 1977, p. 67) that considers "metaphorically" how features of a [classroom] environment support learning. Applying this theoretical framing in a deductive way provides insight into what might be physical or biological that affects learning. We assumed the classroom, with scientific equipment and everyday materials provided physical artefacts for the students to consider and engage with. Just as particular habitats (that might be found in a classroom) have differing niches or places with which a learner can interact. The desktop computer providing a 'goto' reference corner; the iPads and sensors on the mobile trolley or the stack of kindles loaded with children's fiction on the shelf by the window each offer different affordances and potential for learning. The reference computer connected to the internet, with a shortcut to google, will offer quite a different opportunity to explore the world, compared with an iPad connected to a temperature sensor or a kindle offering a story about travelling to see the wildlife of Africa. Gaver (1991) suggests how it is not only what 'virtual' buttons [to press] are offered, but also how these are perceived or salient to users. A key element of identifying an affordance is when an action using an object is obvious in an immediate way with minimal mediation or voluntary sensory processing (Tinio & Smith, 2014). Users know what to do with an object without the need for instructions or labels (Norman, 1988), that is the object makes sense to them and affords salience. Culturally then technology and software that is regularly used, including particular 'tools' that are perceptibly available to the user as graphical (or visual virtual objects) become conventionally available and become a direct affordance for the receiver (Gaver, 1991, p. 3). Thus, the affordances of technology are conveyed graphically [with visual aspects corresponding to different software features, like logging into an email system, the user develops familiarity] so that the 'attributes' of the system 'become available for action' (ibid.).

The kinds of attributes that the combination of hardware and software on a tablet offer includes the ease of activating [through finger pressing, swiping and sliding] different elements of the software [which in this case is Explain Everything, 2021] Using touch to select the various menu options from a word processor to create text, a camera to photograph objects or video events or even audio recorded reports of observations are salient for users who regularly use tablet technology. The ease with which users utilise these affordances can develop over time as they have become enculturated into routinely capturing their thoughts through tapping the word processor or selecting the camera icon to photograph a significant or notable event as it occurs. In other words, what the tablet technology offers is taken-up by the students, which in turn is shaped by their personal histories [and previous practices] of learning with technology. As Rogoff (1995) would describe, users appropriate a way of working with such an artefact, and intuitively and actively utilize what it offers them.

The use of the camera to video record observations, the audio-recording facility, all features embedded into the EE app are all forms of affordances of a haptic, visual and auditory nature. Besides the graphical or visual affordances that tablet technology offer, Webb (2005) also noted specific scientific affordances of technology including the ways that teachers framed learning tasks through the directions they provided that included instructions to think, predict, exchange ideas, investigate, compare, explain, apply and justify.

Students working collaboratively using technology can support an enculturated way of interacting. This promotes peer mediation of ideas and actions of and for each other. Therefore, as Gibson suggests that, 'to perceive an affordance is not to classify an object' (Gibson, 1979, p. 134) or indeed, as Day and Lloyd (2007) affirm, it is not about just the inherent properties of technology that provide opportunities for learning. In this project the human or 'hidden' affordances (Achiam et al., 2014) that are 'perceptible' and 'offer complementarity of action' (Gaver, 1991) were also considered in the ways they were made available for learning. As Gibson (ibid.), suggests, 'The fact that a stone is a missile does not preclude that it can be other things as well. It can be paperweight, book end, hammer, pendulum bob. It can be piled on top of other rocks and make a cairn or a stone wall. …. Arbitrary names by which they are called do not count for perception'. The iPad and the EE app, therefore, offer more than the advertised functions, there are hidden affordances.

Students, therefore, engaging with the technology and working collaboratively on inquiry learning tasks, are thus presented with both physical and human affordances. As Gaver (1991, p. 1) describes 'Affordances are properties of the world that are compatible with and relevant for people's interactions'.

### *16.2.2 Scientific Inquiry*

Inquiry has been globally recognized as an important learning experience for students in schools. It is an authentic way for pupils to experience making sense of the world around them (Bevins & Price, 2016; Braund & Reiss, 2006; Roth, 1995) and develop a better understanding of the nature of science (Crawford, 2000; Erduran & Dagher, 2014). It can also provide the opportunity for children learning science to become enthused (Minner et al., 2010). Inquiry has historically held a coveted position in science learning, as Osborne (2016: 220) cites Burke declaring, "I am convinced that the method of teaching which approaches most nearly to the method of investigation, is incomparably the best…… it tends to set the reader himself in the track of invention, and to direct him into those paths in which the author has made his own discoveries".

The policy in the English National Curriculum, outlining how students should work scientifically (DfE, 2014) in schools, identifies particular kinds of inquiries that should be offered in schools, including:

- observing over time;
- pattern-seeking;
- identifying, classifying and grouping;
- comparative and fair testing (controlled investigations); and
- researching using secondary sources.

It is suggested that, through these kinds of experimental approaches children will become equipped with the scientific knowledge (and skills) to understand the uses and implications of science, today and for the future.

Pedagogically, Harlen (2014) identifies how the development of the kinds of inquiry skills outlined above with younger pupils, particularly, presents a range of challenges for teachers. Inquiry, she argues, extends well beyond just ‘practical work’ or ‘hands-on’ experiences and is not just concerned with children ‘discovering’ for themselves, but is concerned with the development of an array of skills. The particular abilities that Harlen (2014) highlights include:

- raising questions, predicting and planning investigations;
- gathering evidence by observing and using information sources;
- analysing, interpreting and explaining and
- communicating, arguing, reflecting and evaluating.

Ofsted (2013 pp. 10–11) recognises that these types of skills, including pupils evaluating and drawing conclusions from their science work, is limited and that this, particularly in primary schools is underpinned by teachers’ lack of expertise. Evidence of this kind suggests how there are lingering issues with inquiry, not least that teachers do not fully understand and appreciate the nature of it (Minner et al., 2010); that they often (unwittingly) provide far too much ‘help’ and ‘support’ in the preparatory activities for carrying it out (Johnston, 2007) and thus ‘lessen’ the cognitive and affective demands of it…and perhaps even render it more of a ‘verification’ activity; or conversely they may elicit a range of burgeoning questions and queries from the children or students and then ‘prescribe’ the best way for the whole class to investigate one of the emergent questions. Therefore, the extent to which inquiry skills (of aligning a query, developing a rigorous plan to investigate it, independently collecting evidence and then synthesizing meaning from the data) may not be fully developed or key elements may be missed.

Teachers reflectively, can mis-understand and/or mis-judge their pedagogic aims (Johnston, 2014; McMahon & Davies, 2003). Appreciating the ‘real’ extent to which autonomy or agency is afforded to the learners, can range from very ‘teacher-directed’ or ‘teacher-led’ as in a closed inquiry, intended to demonstrate or practice a particular inquiry skill, through to ‘teacher-guided’ or, at the other end of pedagogic spectrum, an open inquiry that is entirely ‘student-led’. Tablet technology affords a range of opportunities for pupils when carrying out inquiries (McGregor et al., 2016) to work independently of the teacher. They are able to collaborate, make-decisions about data collection and analysis, become reflective and reflexive (altering their method or analysis as appropriate) because, for example, they can easily ‘re-wind’, review, reorganise or re-record their experimental work on the tablet.

In this study, we were keen to elicit how the teacher perceived the affordances of the tablet technology and organised ways of working for the students within the classroom setting. We also explored how the students, in turn, understood the affordances that the tablet technology made available for them. We acknowledge that we focused on classroom dialogue because it is highly relevant, but we also paid attention to the nature of interactions [with the technology and between peers] to inform how the learning discourse emerged (Rogoff, 1995, p. 142).

The research concerns that were uppermost in our minds involved exploring how teachers' and students' experiences and understandings about how the utilisation of tablet technology for scientific inquiry differed. We were also interested in lesson enactments that illustrated how the affordances were made available and utilised. Finally, we were interested in whether there were any recommendations, emerging from this study, for teachers organising classroom settings that utilise technology to enhance STEM inquiry learning?

## 16.3 Methodological Approach

This research was carried out within a qualitative-interpretive paradigm. This approach was adopted to help make sense of the everyday and socially complex world found within the educational environment (Merriam & Tisdell, 2015). The aim being to explore the nature and uptake of the perceived and hidden affordances in inquiry contexts. A range of research methods were utilised to probe (Mitchell, 2006) the nature of learning with and without the affordances that tablets provided. We also examined the way the teacher's approach framed and mediated eight year-olds carrying out inquiry activities involving practical tasks that challenged them. The young students were tasked with finding out what they could about the properties of different materials (e.g. maltesers, rice, pasta, soil, magnets). They were provided with some scientific equipment including a sieve, funnels, filters, a magnet, jars and the EE app to record their investigation. Reflective discussions with the researchers after the series of lessons involved explored how the teacher and student perspectives of the use (and application) of iPads and the EE app in science supported both teaching and learning. With a focus on physical and hidden affordances, as elicited through the participants vocalised thoughts the data was collected and subsequently analysed over two 90-min episodes to answer the research questions. They were:

*How does access to tablet technology affect the nature of teaching and learning in a STEM inquiry?*

*How do affordances offered through using tablet technology within a STEM inquiry support learning?*

## 16.4 Research Design

To respond to the research questions the impact of learning *with* and *without* an iPad was examined through a comparative case approach.

That is, two lessons based on the topic of *Materials and their Properties* were videoed (one was a hands-on inquiry, without any access to technology and the other involved the use of tablet technology and the EE app). In the lesson, where iPads were provided for the students who worked in pairs, sharing a tablet between them. Contrastingly, the other lesson without the use of the iPads, was structured in such a way that the pupils had the same set of apparatus but only their science books to write notes, observations and their results. Both sessions invited the same paired pupils to separate a pre-prepared mixtures. In both lessons they were challenged to separate different mixtures. The substances in the first lesson included milk, rice krispies, salt and iron filings. The substances in the second lesson included water, maltesers, lentils and sand. Setting up similar situations for learning in sequence to contrast the nature of classroom interactional processes has been applied previously (McGregor et al., 2020).

## 16.5 Participants

The study reported here involved a class of 30 young students in an elementary school in Oxfordshire. The school was large, with over 300 students from age 3–11 years. The ethnic make-up is 80% White British with other smaller proportions of Irish, White and Black Caribbean, African and Asian descent. It was Ofsted (the National Office of Standards in Education) rated ‘good’ (Ofsted, 2021). The class involved participated because the teacher who was the ICT co-ordinator, had in the previous year embedded the use of the iPad tablet and the software, the EE app, into all her teaching. Therefore, the whole of the mixed-ability class, in year 4 (when they were eight/nine years old) became conversant with adopting the technology whatever they were learning. The whole class were observed naturalistically over the two lessons (amounting to around 180 h). To provide more specific details about the observed processes of teaching and learning, video cameras were set-up around the perimeter of the room with a view to being able to watch more closely (focus on dialogue and inter-action) 3 different pairs in the class. The teacher and those more closely observed young students were interviewed after the videoed lessons with a view to exploring how they each understood the iPad (and the EE software) had afforded opportunities to engage in the scientific inquiry tasks.

## 16.6 Data Collection

This took place in two phases. The first phase involved lesson observations, not only of the students, but also the ways that the teacher conducted the various stages of the inquiry activities. These were all captured via video and audio-recordings. The second phase involved interviewing both the teacher and some of the students after the lessons had been observed.

### *16.6.1 Observations (Classes with and Without Tablet Technology)*

Observations of the two science lessons focused on scientific inquiry that were sequentially taught within the topic, 'Materials and their properties' were carefully framed. This included the students being invited to examine a range of mixtures, dissolving different solids in solutions and also separating solids and liquids). During the latter science lesson all 30 students were invited to use the EE app, pre-installed on their iPads, to capture photographs of their experimentation, record events through the videoing facility, note changes numerically to graphically present changes, audio-record their discussion about their own findings and collate all the different media forms by which they enacted and interpreted what they found within an EE file. One iPad tablet was provided for each girl and boy pairing. After the lessons, the EE files were uploaded to a class dropbox, for the teacher to feedback on. The science lessons, and more specifically three pairs of boy-girl couplings, were videoed and each of the six pupils also carried Dictaphones in their pockets connected to lapel microphones. The student's interactions were captured audibly and on video because, as Brown et al. (2016) noted there was a need for us as researchers to understand how students conceptualised and pragmatically utilised the digital technology. The video and audio data that captured a clear chronology of activities in the two lessons, with and without the students using tablet technology was fully transcribed and annotated so that the socially complex worlds could be made visible through forms of co-constructive (verbal and actional) interactions (Denzin & Lincoln, 2011). This was a necessary step because, not only is there a paucity of research involving the direct observation of the use of iPads in the classroom (Bixler, 2016), this rich data set could examine the nature of the interactions and affordances offered between the pupils and their shared tablet technology as well as suggest how a lack of technological support affected inquiry learning.

### *16.6.2 Interviews*

Post-lesson audio recorded interviews provided interviewees' perspectives regarding implicit and experienced affordances offered via the use of the tablets and EE. Perspectives were elicited from both the teacher and students to explore how and if their understandings about technological affordance in inquiries differed. The teacher was interviewed independently, away from her class. We were not solely concerned with the teacher's perceptions of inquiry learning with and without tablet technology. However, her views about the progress of the young students in her lessons and the different ways she had scaffolded inquiry activity with and without technological support was of key interest.

The six pupils, observed most closely, were interviewed in their pairs after the lessons, so that their recollections and understandings about the use (or lack) of technology would flow and emerge more naturalistically, enabling them to collaboratively spark off each other's thoughts and memories and provide a more in-depth description of events. The questions they were invited to respond to related to their experiences of using an iPad (or not) during their science lessons. Semi-structured interviews have previously illuminated secondary school teacher's views about the integration of these hand-held devices (Lewis, 2018) and they have previously proved insightful when contemplating how primary and secondary teachers' have employed iPads in their classrooms (Hilton, 2016; Jack & Higgins, 2018; Vu, 2013). However, there are relatively few reports of the student's own perceptions of digital technology relating to the utility of iPads using this method of data collection. That is, when students were invited to articulate their views on this subject it was reportedly collected through questionnaires (Soffer & Yaron, 2017) and not interviews.

The semi-structured interviews with both teacher and paired pupils included 16 and 11 open (verbal) questions respectively, which were designed to explore resonance or juxtaposition in their perspectives of tablet affordances. The teachers' questions focused on the general use and advantages of the iPad for teaching science; how they believed the affordances offered by the iPad augments scientific learning; what they thought the EE app offered the teacher and the pupils; and explored what the teacher considered was omitted when the iPad and the associated apps is not used during the science lesson. The pupils were invited to answer questions related to the nature of the affordances (actional and verbal) the Ipad and EE app offers and how this help them learn science; what the difference was between learning science with and without the iPad and what they felt they missed out on when they did not use an iPad.

The teacher and pupil views (from both data sets) were subsequently triangulated to corroborate any articulated illustrations of the affordances offered when teaching and learning science through this technological interface. These interviews not only allowed for a comparative case study between student pairs and the teacher, but also enabled the justification and tentative validation of views which related to the direct impact of the iPad in a primary school science lesson.

## 16.7 Data Analysis

The dialogue in the lessons that was audio-recorded during the lessons, the post observational interviews and those that took place during the science lessons were all fully transcribed and analysed through four phases.

1. Observational analysis was both inductively and deductively analysed. For the inductive analysis a timeline of teacher and learner events was collated. For the deductive analysis an analytical framework that identified the nature of affordances, physical and material (Gibson, 1977; Hammond, 2010; Norman,

| |
|---|
| A mixture is two or more objects (food) that are combined together which can separate. A soluble solid is a solid that dissolves in cold or hot water. An insoluble solid is a solid that doesn't dissolve in any water. The best way to separate an insoluble solid from a liquid is use a small whole sieve then use a filter if you have a lot of time. I think sieving it and filtering it is the best way of doing it because most of the big parts of food comes out for the sieve and any liquid would be out if you filtered it. [You are left with the solid in the filter]. |

**Fig. 16.1** Excerpt from student A's exercise book

1999); pragmatic and sequencing relating the geometric (Achiam et al., 2014) and Hidden, both intentional and cognitive (Achiam et al., 2014) was applied to the observations noted.

2. Dialogic analysis focused on talk between the teacher and learners (Alexander, 2008).
3. Deductive analysis of the dialogue between the paired students. This was considered inductively and deductively (for different types of talk including disputational, cumulative and exploratory) (Littleton & Mercer, 2013).
4. Reflective interviews with the teacher and learners (eliciting their views about the ways the iPad offered affordances) were also deductively analysed by adopting the same analytical framework as described in phase 1.

In summary the initial examination of data was inductive, that is, the transcripts from all four interviews (One teacher and three pairs of children) and the observations were thematically analysed (Braun & Clarke, 2006). Finally, they were inspected (and coded) for various affordances offered by the iPad, namely: sensory, cognitive and physical-geometric.

This enabled the establishment of clear links between the research questions and the summarised research findings below (Thomas, 2013). That is, the synthesis of fuzzy generalisations (Bassey, 1999) were suggested [because this is an exploratory study, not a positivist one involving the collection of numerical data that could be statistically analysed]. The data relating to the impact of the iPad and the affordances that were offered by the use of these hand held devices [has been proposed through synthesis of data that informs Fig. 16.1] when considering teaching and learning science, from not only the teacher's perspective but also their pupils.

## 16.8 Ethics

Ethical approval was granted at university faculty level and consent from the school was sought and obtained from the Headteacher, teacher, parents and the young participants. Prior to the interviews, consent forms were signed by the teacher and the parents, on behalf of the child.

## 16.9 Findings

In comparing the science lessons with and without the tablet technology it became apparent that there were notable differences in the ways that the teacher prepared for the practical activities and also the ways that the students engaged with scientific inquiry (see Table 16.1).

The forms of engagement identified in Table 16.1, when the data was scrutinised more closely, also illuminated how the nature of talk differed, the extent of scientific thinking appeared to be constrained without the iPads, and how the quality of hand-written reports was much briefer and less detailed [in a methodological, observational and interpretative sense] than the EE files produced (see Figs. 16.1 and 16.2).

**Table 16.1** Relative differences noted in contrasting the two lessons with and without a tablet

| Forms of student engagement | Lesson without tablets available | Lesson with tablets available |
|---|---|---|
| Time spent discussing ideas | Less | More |
| Time spent writing | More | Less |
| Time spent quietly working solo | More | Less |
| Time spent collaborating (i.e.: inter-acting to achieve the learning task) | Less | More |
| Time spent videoing/photographing | Less | More |
| Time spent manipulating report on tablet | N/A | More |

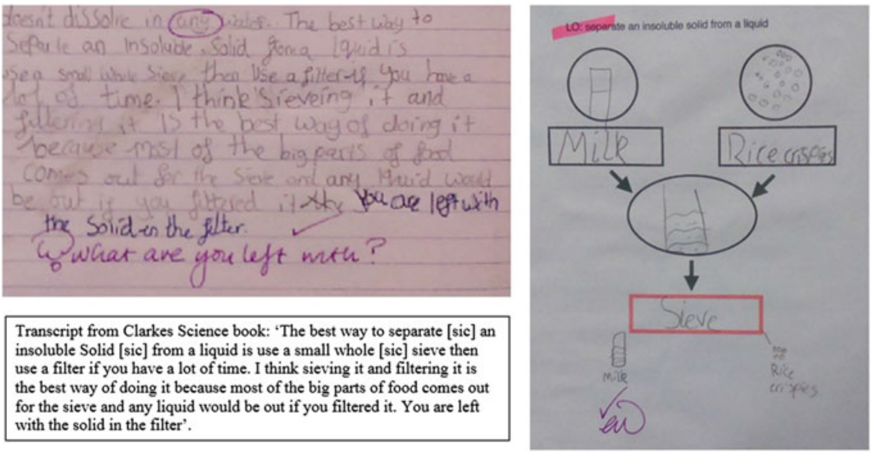


**Fig. 16.2** Excerpt from C's exercise book

This is in stark contrast to the quality of observation, reporting and conclusion-making that was evidenced in the lesson through the portable digital technology, via the EE app.

1. Differences in the nature of talk, both between the students and the teacher and the learners.
2. Evidenced differences in thinking.
3. Quality of reports produced.
4. Contrast in pedagogic preparation.

The types of open-ended tasks, offered through the embedded application promoted opportunities for exploratory discussion; this was reportedly because the pupils were also afforded the opportunity to work more collaboratively and independently of the teacher. That is, the digital assist appeared to enable groups more time and space to develop and apply a wider range of scientific explorative strategies. The lesson where digital technology was not available appeared to be less thought provoking with the children heard nominally talking about equipment to use and its location.

The teacher also noticed how her preparation differed for the two types of approach. The way she engaged the pupils in thinking about inquiry was constrained without digital technology. She realised that utilising the exercise books as the record of the planning and experimentation distracted the children from the science because they were more concerned with writing rather than thinking and doing. She also noted that learner agency was more effectively promoted because the children were more able to work independently.

The students' post-lesson reflections on learning with the technology supported the notion that they were more agentive, and felt more extensively in control of their science endeavours because they were afforded both cognitive and material (and physical) learning opportunities. Therefore, the iPads afforded opportunities beyond that which they experienced with only the exercise book and science apparatus. They appeared to feel they were acting and thinking more scientifically when armed with digital technology.

Interestingly, the third perspective or the non-participant observers noted additional affordances that neither the teacher nor the children paid attention to.

### *16.9.1 Observations of the Learning with and Without a Tablet*

In both the lessons observed, there was much practical activity as indicated in Fig. 16.3a, b.

In the lesson without the tablet technology the students spent much more time writing in their exercise books. Interestingly, the scientific vocabulary, the details of their own inquiry observations and the extent of their thinking was not reflected in these hand-written reports. Although the students were accustomed to documenting

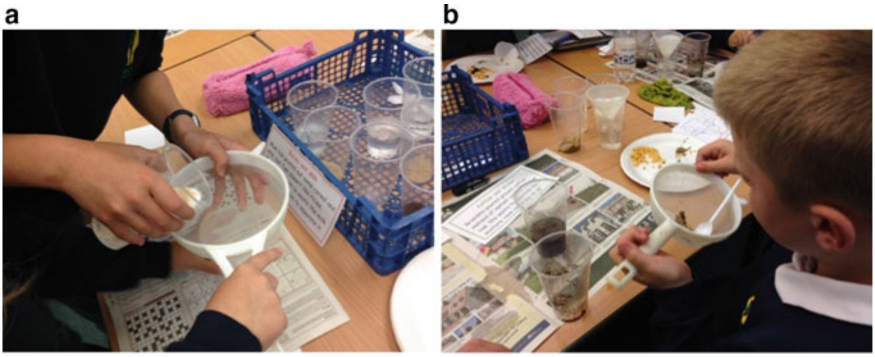


**Fig. 16.3** **a**, **b** Indication of the nature of practical activity undertaken

the work, their written work in the lesson without the tablet technology was much more limited (see Figs. 16.2 and 16.3). However, the nature of reporting was much more varied in the EE files on the tablets. They included photographs, video clips, audio and textual explanations in the inquiry reports (as indicated in Fig. 16.4a–d).

Contrasting the nature of talk in these lessons, with and without tablets indicated there was less general discussion (which was confirmed by analysis of the lesson

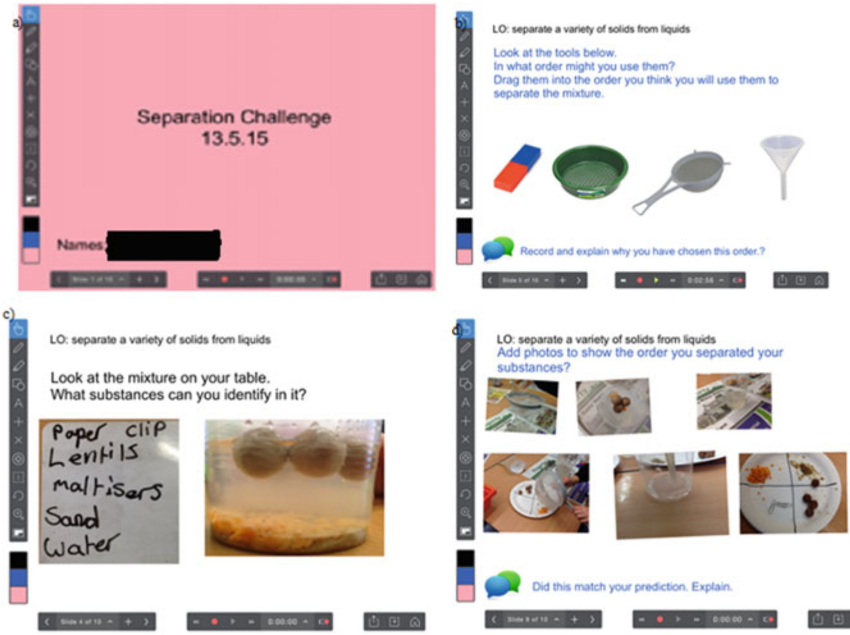


**Fig. 16.4** **a**–**d** Excerpts from student B and C's EE file. Indication of the range of different kinds of information in it

**Table 16.2** Example of comparison between the same pair of students, with and without the tablet available

| Types of verbal exchanges | Without tablet available | Frequency tally | With tablet available | Frequency tally |
|---|---|---|---|---|
| 'I think…' | I think … | 9 | I think … | 2 |
| '…because…' | Because … | 3 | Because … | 2 |
| Questioning of each other | Student C | 6 | Student C | 22 |
| | Student A | 7 | Student A | 37 |
| | Total no. of open questions | 6 | Total number of open questions | 59 |
| Focus of exchanges | 'Filter' | 7 | 'Filter' | 12 |
| | 'Funnel' | 1 | 'Funnel' | 2 |
| | 'Sieve' | 5 | 'Sieve' | 16 |
| Total words uttered during lesson | In 1 h; 20 min | 2391 | In 1 h; 17 min | 3321 |
| Reflection within talk | 45% of talk | 1075 | 55% of talk | 1827 |

transcripts) and more quiet individual working when the students did not have access to the tablet technology.

From analysis of the lesson transcripts (with comparative excerpts provided in Table 16.2), it became clear that, when the tablet technology was not available, there surprisingly appears to be more 'I think …..' and …'because…' (Mercer, 1999) comments exchanged between learners. Deductive analysis involving examination of the kinds of utterances exchanged between the students indicated to some extent how they, (i) worked together (through analysis by applying Mercer's three types of talk, disputational, cumulative and exploratory), and, (ii) what kind of collaborative co-constructive thinking they were engaging in (Littleton & Mercer, 2013).

It was intended that this analysis would shed light on the nature of speech-acts the students engaged in and whether there were notable differences when an iPad was the medium by which the inquiry activities were documented. The analysis looked at three kinds of talk, informed by Mercer (2008), considered firstly 'disputational' discussion characterised by a lack of shared perspectives or 'constructive criticism' (Mercer, 2008:1) that often features one dominant voice. Secondly, 'cumulative' talk, whereby 'everyone simply accepts and agree[s]' with what the others say, in doing so they make what they think available for others, but they do so in an uncritical way lacking elaboration and evaluation. Thirdly, 'exploratory' talk was also considered, that is dialogue whereby the exchanges make explicit alternate views and justifications that may even reach an agreed perspective (Littleton & Mercer, 2013). Interestingly when tablet technology was absent, there was much less questioning of each other, but the more disputational type statements, including the 'I think…' and the 'because…' claims. The discussion focus was centred more on what equipment they needed (such as, filters, funnels and sieves) and where to get it from. The transcriptions indicated how scientific terminology was used much more apparent in dialogue between the pairs of students using tablet technology. However, when using a tablet, there appears to be less 'I think …..' and …'because…' comments between the pairs of students. With one pair, 'I think…' was only uttered twice and '…because…' was only used twice. However, when the dialogue was analysed for verbal exchanges that demonstrated asking each other open questions (Siraj-Blatchford & Manni, 2008, p. 14) there was more dialogue that demonstrated questioning each other about aspects of the task, including how they carried out the method and how to best explain and capture it through pictures, or video, text and audio. The proportional utterances of scientific words in context was less, but overall there were more words exchanged in the lesson. A breakdown of the frequency, or overall percentage, of these types of verbal exchanges, from the transcripts, can be found in Table 16.2.

### *16.9.2 Teacher Interview*

The interview with the teacher elicited a range of perspectives not only about how she used iPads specifically for teaching the science lessons we observed, but also about how tablet technology supported learning generally. Interestingly she explained how, for inquiry science, the tablet, 'allow[s] them to review not just what they've done but I think it allows them to, if you've given them some stimulus allows them to predict. So, I think it's […] personalising their views on what is going on because if I just show one thing on the board it's not quite as focused as two children focusing on something in-between them that they've then got that ability to talk [about]'. She then shared how, even if she used technology of a different kind it didn't necessarily scaffold the young students working independently. She stated that, 'If I just do a powerpoint I can skip through it, I'm in control'. She was very aware of generating opportunities for all students to engage in the inquiry activities, she explained, 'If I'm more specific about what I want the objective to be, also […] thinking more clearly about the differentiations […] of children who can't read, who can't access, who […] don't have a background knowledge that they can bring to help and I give that to them, […] I allow them to access things in, in a similar [way] or give them something that allows them to almost catch up where I know those other children potentially are. Then […]they're working through more independently.' She recognises, too how being able to work independently is important pedagogically, through the way she 'sets-up' the tasks 'without being too prescriptive, so I don't want them to work only to provide answers', she designs the activities so that they are 'a little bit open ended'. She also appreciates how the tablet technology enables and supports development of many aspects of scientific inquiry, like, 'making systematic and careful observations'; 'gathering, recording, classifying and presenting data in a variety of ways to help in answering questions' (DfE, 2014, English, National Curriculum), through the technology allowing varied ways of visually recording and presenting videoed or photographed reactions or events. She says, 'because of the ability to slow things down. I think, you […]put it in video, the video you can slow mo it. So, for example two liquids mixing food colouring and water or even, even a solid like coffee granules and water, it's, it's ten seconds and the coffee granules are dissolved and you've got a solution haven't you […] so, it's the fact that they could slow it down and see that as the coffee granules were dropping actually they were starting to dissolve already', 'they notice odd things' and 'more scientific explanation [can] come from someone else rather than me'. The use of the iPads, was recognised by this teacher to offer (different layers of) affordance for her learners. She recognised that within the process of learning, the tablet technology afforded:

- Ways of being reflective about learning experience(s) to explain what has happened or what has been done;
- Ways of 'transforming' their thinking (about science) for different audiences [themselves, each other and the teacher];
- Ways of replaying happenings and/or events including changes of state, dissolution, evaporation etc.;
- Ways of reviewing the claimed outcomes of experimentation;
- Ways of verifying if others have found similar behaviours of materials;
- Ways of reporting the outcomes of inquiry activity that affords more personalisation of the science.

These resonate with Drennan (2019, p. 42) who, as a researcher eliciting how tablet technology afforded effective pedagogical use, highlighted *reflection*, *transformative teaching*, *generative activity*, *situatedness* and *appropriateness* of ICT use.

As Drennan (2019, p. 42) suggests, it is the way the teacher uses the technology in their teaching, not the 'what they do'. In this study we are emphasising the outcomes from learning similar subject matter with and with-out the use of technology. This suggests how pedagogically the teacher made a particular range of affordances of the technology available for the students to utilise for learning.

### *16.9.3 Students' Views Elicited Through Interviews*

After the lessons which were observed, the students were asked about the ways they thought the tablet technology helped them learn in science, especially inquiry activities. In summary the kinds of affordances they paid attention to included how the combination of hardware and software enabled them:

- To find about things they were unsure about [via the internet];
- To check and verify their understanding of scientific words [via the internet];
- To collate useful library images when need to generate illustrations;
- To be able to easily plan, explain what done [with different equipment], the steps in the inquiry;
- To pay more detailed attention than normal to the sequence of activities;
- To take lots of photographs of what was being done (and upload to dropbox);

- To use audio-recorded speech to verbally explain what was done;
- To annotate diagrams explaining what was done.

The specific kinds of comments they made are included in a summary table (see Table 16.3) of affordances.

**Table 16.3** Student's views of affordances offered through the use of tablet technology and EE software.

| Physical attribute provided by tablet (and EE) in the learning environment | Generalised nature of affordance | More specific inquiry learning and learner affordance | Related student comments |
|---|---|---|---|
| Small size and long battery life (portability) | Learning can be ubiquitous, flexible and polysynchronous (not time bound)[a] | Data can be gathered anytime, anywhere about almost anything within the classroom | "pairs better than as individual (think harder on your own)..and quicker if work together" |
| Touch screen | Fingers control use (no peripherals like mouse, keyboard etc.) | Easy manipulation to engage in different aspects of inquiry including;<br>(i) observation over time;<br>(ii) looking for patterns;<br>(iii) identifying groups or classifying objects or events;<br>(iv) compare or contrast things and research existing data sources | "move pictures around easily"<br>"enables personalized way of working"<br>"offers customized learning resource"<br>"more at hand (don't have to fetch books)…"<br>"do things quicker" |
| Intuitive interface | Easy manipulation by tap and swipe<br>Learn through using the technological capability, not learning about how the technology works | Immediate data capture in a variety of forms that can be manipulated into illustrations, video, photos, textual or tabular forms, graphical displays etc. | "everything just there"<br>"Search better words"<br>"flexible to change things"<br>"can verify words/terms/objects don't know/not sure about" |

(continued)

**Table 16.3** (continued)

| Physical attribute provided by tablet (and EE) in the learning environment | Generalised nature of affordance | More specific inquiry learning and learner affordance | Related student comments |
|---|---|---|---|
| Integrated audio and video software that enable multi-media software (EE) | Various visual affordances [video/photographic/images/texts];<br>(i) Video recordings<br>(ii) Still photographic recordings<br>(iii) Replay and slow-motion re-viewing of events and phenomena<br>(iv) Audio-digital recordings<br>(v) Textual input<br>Other sensory [auditory and haptic] affordances | A range of inquiry practices supported including;<br>(i) Raising questions;<br>(ii) Gathering evidence;<br>(iii) Analysing, interpreting and explaining;<br>(iv) Communicating, reflecting and evaluating | "if don't have ipad cant film it—like chocolate melting…if you have to remember it—it just goes out of your head!"<br>"with ipad don't have to remember what you say to write it—can record it frustrated if don't have an ipad"<br>"correct mistake (or something wrong) more quickly"<br>"instead of writing can talk it"<br>"neater writing/text to explain/describe things/what done"<br>"record sound/voice"<br>"'zoom' in on things to see more detail" |
| Connection to apply TV | Easy whole class viewing of same screen | Whole class viewing to verify and validate nature of a range of inquiry practices (see above) | "'zoom' in on things to see more detail" |
| Connection to dropbox | Easy exchange of large multi-media EE files | Learning from each others' inquiries | "remember/archive stuff (in dropbox)" |

[a] Excerpt from Drennan and Moll (2018), p. 125

## 16.10 Discussion

Within a socio-cultural perspective of learning, the tablet technology offers affordances that promote working scientifically (and consequently enable enhancement of inquiry skills and understanding of aspects of the NOS).

The teacher recognises that the tablets support more in-depth and focused reflection on scientific phenomena for the students when they are engaged in inquiry learning. It is notable that reflections evidenced from the transcripts [researcher's perspective] as indicated in Table 16.2 illustrate how tablet technology affords more interactivity between learners demonstrated by the increase in open questions exchanged, the focus of scientific exchanges and the extent of talk concerned with scientific method, explanation of inquiry and varied means [photo/video/text/audio] by which they record the events of their experimentation. The nature of the students' talk is more exploratory, that is asking each other about what they think, rather than disputational whereby one student's views, directions and actions predominate over another. The teacher's comments in the interview verify that iPads can promote scientific literacy and a general increase in discussing aspects of scientific inquiry. Although the teacher recognises the review and recounting process scaffolded by the iPads, the researcher perspective offers more in-depth detail because the transcripts offer evidence of the nature of dialogue rather than re-collections of it. The transcripts from the student's audio-recordings also allow analysis of the use of scientific terms and whether or not they are applied in context and consequently offer examples of scientific literacy.

In contrast the students focus a little differently on the affordances iPads extend to them. Their juxtaposed perspective indicates how as users of the technology we [teachers and researchers] should take account of their views (Ruddock, 2007). They appreciate and understand how different aspects of the physical environment generated by the technology (tablet and EE software) affords different kinds of possibilities. These are summarised in Table 16.3.

## 16.11 Conclusion

So, although the practitioner's reflections, researcher's observations and students' views differ a little in focus there are key common features emphasised that tablet technologies offer when learning about and through inquiry. Table 16.3 summarises a range of ways in which inquiry practices can be engaged in (and are even recognised by the students). Interestingly though, in discussion with the teacher and her students, there were some differences in the ways affordances for scientific inquiry were perceived. We offer a model (Fig. 5) that suggests how teacher and student views relate but also differ.

Digital technology involving touchscreen, photo capture and audio recording that can be easily integrated offers enhanced sensory, physical-geometric and cognitive affordances that can enhance inquiry learning in STEM. It would be helpful for teachers to be aware of these and consider carefully how they make them available without prescribing how to use them.

Interestingly, this model could not be conceptualised without the data collected from the three juxtaposed perspectives of teachers, young learners and non-participant observers to develop and offer a proposition about the ways that digital technology can augment learning.

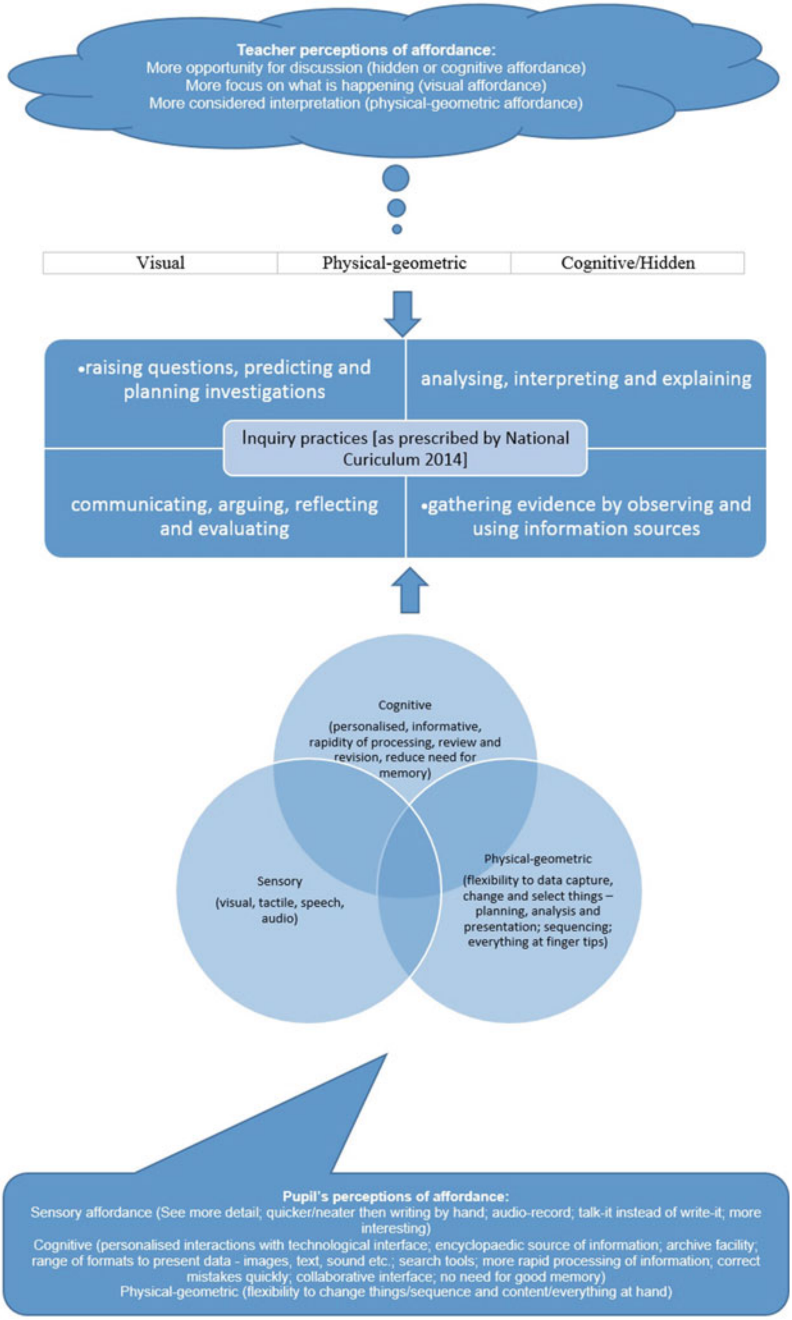


**Fig. 16.5** Teacher and pupils' perceptions of affordance.

This exploratory research offers insights that are useful for pre-service, in-service teachers, teacher-educators, researchers and policy makers who influence ways resources are made available, provide curricular guidance about how to use technology and mediate ways beginning and qualified practitioners develop their practice.

## References


Achiam, M., May, M., & Marandino, M. (2014). Affordances and distributed cognition in museum exhibitions. *Museum Management and Curatorship, 29*(5), 461–481.

Alexander, R. (2008). *Essays on pedagogy*. Routledge.

Bevins, S., & Price, G. (2016). Reconceptualising inquiry in science education. *International Journal of Science Education, 38*(1), 17–29.

Bassey, M. (1999). Case study research in educational settings. Buckingham: Open University Press.

Bixler, S. G. (2016). *One-to-one iPad technology in the middle school mathematics and science classrooms*. University of Kentucky.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Braund, M., & Reiss, M. (2006). Towards a More Authentic Science Curriculum: The Contribution of Out-of-School Learning. *International Journal of Science Education, 28*, 1373–1388.

Brown, C. P., Englehardt, J., & Mathers, H. (2016). Examining preservice teachers' conceptual and practical understandings of adopting iPads into their teaching of young children. *Teaching and Teacher Education, 60*(2016), 179–190.

Chou, C., & Block, L. (2018). The mistmatched expectations of iPad integration between teachers and students in secondary schools. *Journal of Educational Computing Research, 57*(5), 1281–1302.

Clarke, B., & Svanaes, S. (2014). Tech knowledge for schools. An updated literature review on the use of tablets in education. Family Kids and Youth, 9thApril. Available at: https://learningfoundation.org.uk/wp-content/uploads/2016/04/FKY-An-Updated-Literature-Review-on-the-Use-of-Tablets-in-Education-April-2014.pdf. (Accessed 9th April 2020).

Clarke, L., & Abbott, L. (2016). Young pupils', their teacher's and classroom assistants' experiences of iPads in a Northern Ireland school: "Four and five years old, who would have thought they could do that?" *British Journal of Educational Technology, 47*(6), 1051–1064.

Crawford, B. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916–937.

Day, D., & Lloyd, M. (2007). Affordances of online technologies: More than the properties of the technology. *Australian Educational Computing, 22*(2), 17–21.

Denzin, N. K., & Lincoln, Y. S. (2011). *The Sage handbook of qualitative research* (4th ed.). SAGE.

DfE. (2014). *National curriculum for England*. Available at: https://www.gov.uk/government/collections/national-curriculum. Accessed 12th September 2021.

DfE. (2019). *Realising the potential of technology*. https://www.gov.uk/government/publications/realising-the-potential-of-technology-in-education. Accessed 15th July 2021.

Drennan, G., & Moll, I. (2018). A conceptual understanding of how educational technology coaches help teachers integrate iPad affordances into their teaching. *Electronic Journal of e-Learning, 16*(2), 122–133.

Drennan, R. L. (2019). Digital Portfolio Use in the First-Grade Classroom: Perceptions of Seesaw. Masters of Education in Teaching and Learning. *23*. https://digitalcommons.acu.edu/metl/23

Edwards, A. (2000). Looking at action research through the lenses of socio-cultural psychology and activity theory. *Educational Action Research, 8*(1), 195–204.

Erduran, S., & Dagher, Z. (2014). Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories. In *Contemporary trends and issues in science education*. Springer.

Explain Everything. (2021). Explain everything software app. Available at www.explaineverythingapp. Accessed 15.6.21.

Falloon., G., & Khoo, E. (2014). Exploring young students' talk in an ipad-supported collaborative learning environments. *Computers and Education, 77*(1), 13–28.

Gaver, W. (1991). Technology affordances. In *Proceedings of the CHI 1991* (pp. 79–84). ACM Press.

Geer, R., White, B., Zeegers, Y., & Barnes, A. (2017). Emerging pedagogies for the use of ipads in schools. *British Journal of Educational Technology, 48*(20), 490–498.

Gibson, J. J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting and knowing*. Lawrence Erlbaum Associates.

Gibson, J. J. (1979). The ecological approach to visual perception. Boston, MA: Houghton Mifflin.

Gomes, J., Fleer, M., & March, S. (2014). Science learning affordances in preschool environments. *Australasian Journal of Early Childhood, 39*(1), 38–48.

Hammond, M. (2010). What is an affordance and can it help us understand the use of ICT in education? *Education and Information Technologies, 15*(3), 205–217.

Harlen, W. (2014). *Assessment, standards and quality of learning in primary education*. CPRT Research Survey 1.

Hilton, A. (2016). Engaging primary school students in mathematics: Can iPads make a difference? *International Journal of Science and Math Education, 16*(1), 145–165.

Jack, C., & Higgins, S. (2018). What is educational technology and how is it being used to support teaching and learning in the early years? *International Journal of Early Years Education, 27*(3), 1–16.

Johnston, J. (2007). What is creativity in science education. In A. Wilson (Ed.), *Creativity in primary education* (2nd ed.). Learning Matters Ltd.

Johnston, J. (2014). *Emergent science: Teaching science from birth to 8*. Routledge.

Lewis, E. M. (2018). *A qualitative study of secondary school teachers' perceptions of iPad intergration*. Capella University.

Littleton, K., & Mercer, N. (2013). *Interthinking: Putting talk to work*. Routledge.

Maich, K., & Hall, C. (2016). Implementing iPads in the inclusive classroom setting. *Intervention in School and Clinic, 51*(3), 145–150.

McFarlane, A. (2019). *Growing up digital: What do we really need to know about educating the digital generation?* Available at https://www.nuffieldfoundation.org/sites/default/files/files/Growing%20Up%20Digital%20-%20final.pdf. Accessed 15th July 2021.

McGregor, D., Bird J., & Frodsham, S. (2016). Mixtures, maltesers and magnets: Augmenting the enquiry process through tablet technology in primary science. Presentation at British Educational Research Association (BERA) Conference, Leeds, UK, 12th September 2016.

McGregor, D., Frodsham, S., & Wilson, H. (2020). The nature of epistemological opportunities for doing, thinking and talking about science: Reflections on an effective intervention that promotes creativity. *Research Science & Technology Education*. https://doi.org/10.1080/02635143.2020.1799778

McMahon, K., & Davies, D. (2003). Assessment for enquiry: Supporting teaching and learning in primary science. *Science Education International, 14*(4), 29–39.

Mercer, N. (1999). *The guided construction of knowledge. Talk amongst teachers and learners*. Multilingual Matters.

Mercer, N. (2008). *Three kinds of talk*. Retrieved from https://thinkingtogether.educ.cam.ac.uk/resources/5_examples_of_talk_in_groups.pdf. Accessed 19th April 2016.

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation* (4th ed.). Jossey-Bass.

Minner, D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474–496.

Mitchell, C. J. (2006). Case and situational analysis. In T. M. S. Evens & D. Handelmann (Eds.), *The Manchester school. Practice and ethnographic praxis in anthropology*. Berghahn.

Norman, D. A. (1988). *The design of everyday things*. Basic Books.

Norman, D. A. (1999). Affordance, conventions and design. *Interactions, 6*(3), 38–43.

OECD. (2020). *Digital strategies in education across OECD countries*. Available at https://www.oecd-ilibrary.org/education/digital-strategies-in-education-across-oecd-countries_33dd4c26-en. Accessed 12.03.21.

Ofsted. (2013). *Maintaining curiosity. A survey into science education in schools* (pp. 22–44). Crown Copyright.

Ofsted. (2021). Ofsted Ratings explained. Available at https://cascaid.co.uk/ofsted-inspection-framework/ratings/

Osborne, J. (2016). Defining a knowledge base for reasoning in science. The role of procedural and epistemic knowledge. In Richard A. Duschl, Amber S. Bismack (Eds) Reconceptualizing STEM Education: The Central Role of Practices. London : Routledge p.220

Robbins, J. (2003). The more he looked inside the more piglet wasn't there: What adopting a sociocultural perspective can help us see. *Australian Journal of Early Childhood, 28*(1), 24–30.

Rogoff, B. (1995). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In J. V. Wertsch, P. del Río, & A. Alvarez (Eds.), *Sociocultural studies of mind* (pp. 139–164). Cambridge University Press.

Roth, W. M. (1995). *Authentic school science. Knowing and learning in open-enquiry science laboratories*. Kluwer Academic Publishers.

Ruddock, J. (2007). Student voice, student engagement and school reform. In D. Thiessen & A. Cook-Sather (Eds.), *International handbook of student experience in elementary and secondary school* (pp. 587–610). Springer.

Siraj-Blatchford, I., & Manni, L. (2008). 'Would you like to tidy up now?' An analysis of adult questioning in the English Foundation Stage. *Early Years, 28*(1), 5–22.

Soffer, T., & Yaron, E. (2017). Perceived learning and students perceptions toward using tablets for learning: The mediating role of perceived engagement among high school students. *Journal of Educational Computing Research, 55*(7), 951–973.

Thomas, G. (2013). *How to do your research project: A guide for students in education and applied social sciences* (2nd ed.). SAGE.

Tinio, P. L., & Smith, J. K. (2014). *The Cambridge handbook of the psychology of aesthetics and the arts*. Cambridge University Press.

Vu, P. (2013). *An inquiry into how iPads are used in classrooms*. Southern Illinois University.

Webb, M. (2005). Affordances of ICT in science learning: Implications for an integrated pedagogy. *International Journal of Science Education, 27*(6), 705–735.

# Chapter 17
# Digital Storytelling in Early Mathematics Education

**Ilkay Ulutas, Ebru Kilic Cakmak, Aysegul Akinci Cosgun, Emine Bozkurt Polat, Feyza Aydın Bolukbas, Kubra Engin, Emrah Kayabasi, and Seher Ozcan**

**Abstract** In recent years, technology has been widely used in teaching mathematics to support students' thinking skills in early childhood. Although there are many online games and applications with mathematical content, the fact is that most of them are limited to particular concepts or acquisitions. Digital storytelling provides a gateway to math concepts and mathematics skills by engaging children in both mathematics and technology. Strengthening the knowledge and experience of teachers according to the latest technological developments will enable them to integrate their digital stories into mathematics education. The purpose of this study was to conduct *Digital Mathematics Stories Training* with early childhood teachers and examine their experiences with this training. At the end of the week-long theoretical and practical training with 30 teachers, it was determined that the teachers experienced increased self-confidence, were motivated toward creativity and production, and demonstrated an enhanced ability to integrate mathematics and technology. During the study, teachers were amazed at the extent to which they advanced their limited digital competencies. Their anxieties transformed into productivity and self-confidence.

**Keywords** Math education · Digital storytelling · Early childhood education

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## 17.1 Introduction

Digital storytelling consists of storytelling elements (text, pictures, narrator, etc.) and digital elements (video, sound, music, etc.) that combine to present information through a cohesive story (Normann, 2011; Robin, 2006). It has become increasingly prevalent in recent years due to its practical and effective nature, its popularity in social media, and its success stories that have gained worldwide recognition (Dreon et al., 2011).

The fact that shares based on digital storytelling have attracted the attention of all individuals, large and small, on social media has drawn attention to the fact that they can be used not only for social purposes but also for educational purposes and has made it widespread in education. It has been observed that the use of digital stories in education increases students' motivation to learn content and, unlike traditional teaching approaches, provides students with the freedom to express themselves in the digitally fluent language of their generation (Hofer & Swan, 2006; Tendero, 2006). Robin (2008) stated that the use of digital stories in education increases the interaction between teachers and students, ensures the effective use of computers, digital software, video, and audio recording tools, strengthens literacy skills, and fosters 21st-century skills (such as cultural, visual, informational, and media literacy). In addition, digital storytelling enables the use of multimedia technologies in the classroom, supports skills such as collaboration and decision-making in the learning process, brings together formal and informal learning processes, and ensures active participation of learners (Clarke & Adam, 2011; Dogan & Robin, 2008; Frazel, 2010; Lambert, 2013; Robin, 2006).

Research reported that using digital stories in the classroom is beneficial for various levels of learning, beginning with the youngest age groups (Foley, 2013; Kearney, 2011; Kocaman-Karoğlu, 2016; Yang & Wu, 2012). In studies that compared digital storytelling and traditional storytelling, it was found that children in the classrooms using digital stories demonstrated a higher increase in motivation than those in the classrooms using traditional stories (Niemi & Multisilta, 2016). These children were more willing to participate in activities (Azizah et al., 2011) and exhibited higher digital literacy and mathematics skills (Maureen et al., 2018; Merjovaara et al., 2020). Moreover, it has been determined that digital stories lead to a significant improvement in children's ability to carry out calculations and solve mathematical problems (Preradovic et al., 2016).

The benefits of digital storytelling in mathematics education continue. Digital storytelling builds children's interest in mathematics, improves their problem-solving skills (Preradovic et al., 2016; Sancar-Tokmak & Incikabı, 2013; Starčič et al., 2016), and enhances their understanding of algorithms and geometry (Niemi & Multisilta, 2016). Digital storytelling can be used effectively in realizing the mathematics learning of disadvantaged children. In addition, digital storytelling increases creativity, curiosity and questioning, discussion, communication, trust, cooperation, and understanding and analysis of information (Foley, 2013; Merjovaara et al., 2020; O'Byrne et al., 2018; Toki & Pange, 2014; Towndrow & Kogut, 2020). When children interact with digital stories, their digital literacy develops, they can reinforce the concepts they have learned, and they can explore different ways of learning (Barret, 2006; Korosidou & Griva, 2020).

Digital stories contribute to the development of thinking, language, listening, visual, and literacy skills in the early years (Bedir Erişti, 2017; Bratitsis et al., 2012; Couse & Chen, 2010; Gözen & Cırık, 2017; O'Byrne et al., 2018; Verdugo & Belmonte, 2007; Vernadakis et al., 2005). Digital stories also aid the development of children's emotional competencies, sorting abilities, and sequencing skills (Agélii Genlott & Grönlund, 2013). Another significant benefit of digital stories is that they can introduce information about cultural heritage into the classroom and transfer intercultural information among students (Tzima et al., 2020). It is a two-way process that contributes not only to children's learning but also to teachers' learning and development.

Digital storytelling is a fundamental pillar of technology integration in education. It is particularly useful in providing technology integration in early mathematics education (Agélii Genlott & Grönlund, 2013). McManis and Gunnewig (2012) stated that employing technology education in early childhood classroom environments has positive results for children if it is (1) developmentally appropriate, (2) includes tools to help teachers apply technology successfully, and (3) is integrated. For this reason, TPACK (2012) identifies three key features for teachers to use as a guide in their approach to integrating technology into education: content, pedagogy, and technology. Effective technology integration requires developing sensitivity to the dynamic, transactional relationship between these components of knowledge situated in unique contexts. In order for teachers to apply this triple component, it is necessary for them to cultivate their understanding of the technological applications and update their knowledge and skills accordingly.

Previous studies have drawn attention to the effective results of technology integration when teacher competencies are supported (Dogan & Robin, 2008; Mishra & Koehler, 2006; Starčič et al., 2016). Teacher self-confidence provides contributions to teacher's practices and integration of the technology to the classroom. It would be possible that if digital self-efficacies of teachers are improved, they will promote technology-infused learning environments (Heo, 2009). Digital story creation involves blending basic digital media skills and creative methods. It therefore contributes to increasing the teacher's professional competencies and creativity. With digital storytelling, the teacher both ensures the integration of technology into education and initiates an innovative application in education. Kocaman-Karoğlu (2016) conducted a study with preschool teachers using digital storytelling. During the study, teachers observed that digital storytelling generated many benefits, such as making the educational process fun, supporting active participation, giving children concrete experiences, and facilitating technological awareness. The teachers did not have difficulty administering the activities but struggled with the necessary theoretical knowledge and technology. It is therefore evident that teachers require additional training in technological proficiency. Çıralı Sarıca (2019) determined that as a result of digital storytelling training given to teachers, they were able to explain themselves better through digital storytelling, their professional skills improved, and they found solutions to the important problems they faced. These results indicate that digital storytelling facilitates growth for both child and teacher. When teachers are equipped to create digital stories, they will be able to take advantage of these benefits and frequently include digital storytelling in their curriculum.

This chapter, which is based on the use of digital storytelling in early childhood mathematics education, is intended to evaluate early childhood teachers' achievements after receiving digital storytelling training. The primary research question is "What are the teachers' achievements regarding digital mathematics education?".

## 17.2 Method

This study was structured as a case study carried out within the scope of the project "*TUBITAK 4005-121B251-We Use Technology in Early Mathematics Learning with Digital Storytelling*." A case study involves an in-depth study of individuals, groups, or events within a particular situation. In the study, preschool teachers were given Digital Mathematics Stories Training that was based on designing digital math stories, and their perceptions, experiences, and levels of digital literacy were recorded during the training process. The educational activities, which took place for a total of seven full days (seven hours a day), were administered by early childhood professors and computer literacy professors.

### *17.2.1 Participants*

Thirty preschool teachers were recruited for the Digital Mathematics Stories Training. Teachers were invited to participate in the study through social media and corporate announcements. All of the teachers were female, and they worked as teachers for an average of 13 years. During the selection process, teachers were required to fulfill two prerequisites: participating as volunteers and acknowledging that they had not previously received similar training. The teachers then gave a statement by filling out the application form . Their statements were examined to determine their skill level in preparing digital materials, openness to developing their digital skills, interest in digital storytelling and mathematics education, and willingness to employ digital storytelling in their classrooms. The statements also collected information about their teaching experience, their gender, and if they worked in a disadvantaged area (families with low economic status, immigrant children, etc.) Finally, 30 primary and 15 substitute participants with heterogeneous characteristics were selected. Their participation in the study was clarified by interviewing the teachers via online platforms and telephones, and substitutes were identified for the teachers who would not participate for seven days.

### *17.2.2 Data Collection Tools and Data Analysis*

In the study, teachers' experiences with digital mathematics stories were evaluated with an interview form. The interview form included questions about teachers' perceptions of digital literacy, their views on digital storytelling, their competencies regarding digital storytelling, their approach to technology integration in mathematical activities, and their knowledge of digital storytelling. At the conclusion of the Digital Mathematics Stories Training, interviews were again held with the teachers to learn if their views on digital storytelling and early mathematics learning had changed after the training. The interviews were conducted one-on-one, and the teachers' responses were recorded both in writing and by voice recording. The data obtained from the interview form were analyzed by content analysis.

### *17.2.3 Digital Mathematics Stories Training for Teachers*

The Digital Mathematics Stories Training activities involved educating teachers in both theoretical knowledge and practical applications regarding technology and digital storytelling over seven full days. The training thus consisted of two parts: theoretical and practical. In the theoretical component, teachers gained a basic understanding of digital storytelling by attending presentations on digital story styles, technology integration in early math education, and the features of digital math stories. In the practical component, teachers were first introduced to the programs that can be used to create digital stories. The seven steps of digital storytelling by Lambert (2013) were then explained to the teachers in order to shed light on the origins of the digital story (Fig. 17.1). This explanation was presented from a mathematics perspective.


**Fig. 17.1** Seven steps of digital storytelling (Lambert, 2013)

1. **Owning the insight**: The main point of the story, the content of the story, what it will be about, and what it will present to the audience is decided (Lambert, 2013). In this step, the teacher determines which mathematics content to focus on by determining the interests and needs of their students (Kearney, 2011). For example, the teacher can devise a story's content to help children who have difficulty distinguishing between right and left, as in the "Address" story. They can also prepare content that develops counting or calculation skills.
2. **Owning the emotions**: Emphasizing an emotion in the story is intended to attract the attention of the audience. It is based on the question of how this story makes the creator and listener feel. Emotions will increase interest in the story (Lambert, 2013). Even if it is a digital story with mathematical content, it is important that it includes emotions to increase the effect. For example, stories can be created by focusing on various emotions. Examples include lovingly counting the kittens, waiting curiously to see how many nuts will fit in the squirrel's mouth, becoming upset when fruit is divided unevenly among a group of friends, and zero that is upset that it doesn't work. The central emotion should be emphasized enough to motivate the solution of the problem and enable the children to follow the story with interest. However, it should not be emphasized to such an extent that it distracts from the goal of learning mathematics.
3. **Finding the moment**: The moment in the story is chosen to answer the question of what key detail will help the audience appreciate the moment of change. In digital math stories, the emphasized moment can be clearly constructed as a certain time (morning, evening, etc.), or the main concept can be emphasized with sound, effects, or movements. For example, while counting in a story, the counted objects can be marked with interesting sounds or the object can be animated as the students count.
4. **Seeing the story**: The story becomes visible through the addition of pictures, emotes, drawings, movements, or other visual aids. This step requires advanced technological literacy, various kinds of visual materials, a creative perspective, time, and patience. Mishra and Koehler (2006) emphasized that teachers need to know not just the subject matter they teach, but also the way the application of technology can change the subject matter (p. 1028). In addition to employing the educator's point of view, the teacher should also adopt the artist's and engineer's

point of view. He/she should determine the program they will use to visualize the purpose of the digital math story and add scenes using the visuals from the program or their own archive. Real-life camera footage or children's drawings are both suitable visuals for mathematics. For example, the teacher can create pictures of children's drawings, elevator buttons, or building numbers for images related to number writing. When visuals are placed in scenes, they are revised and organized in terms of creativity and humor.

5. **Hearing the story**: Voices, sounds, music, or soundtracks are used to complement the story and increase its effect (Lambert, 2013). Another difference between digital stories and storybooks is the sounds and effects. Mayer (1997) suggested that information presented both visually and verbally has a stronger impact on learning than information provided in a single mode. With sounds and effects, the story can more accurately represent scenarios, and the concept of mathematics can be made more appealing. Sounds can take the form of imitation, animation, or natural or mechanical noises—not just presentation, narration, or dialogue. For example, in a mathematical story about high and low sounds, variations can be created with the source and intensity of the sounds. In a mathematical story about finding direction by using echoes, the theme can be emphasized by creating an echo sound effect: right (right, right, right...), left (left, left, left…), forward (forward, forward, forward …), backward (backward, backward, backward…).
6. **Assembling the story**: The content is assessed to ensure that it achieves its purpose while avoiding excessive length that will bore the audience (Lambert, 2013). This step aims to review the created story in terms of visuals, sounds, and duration (Kearney, 2011). Factors that determine the success of digital storytelling include the creativity of the ideas, the correspondence of the chosen digital technique with the content, and the mastery of the digital technique (Hartley & McWilliam, 2009). The story is therefore evaluated to ascertain whether it meets its learning outcomes, whether the visuals and the sounds overlap, and whether the duration maintains interest and is appropriate for the story's purpose. The duration is important because learning in mathematics is based on concrete experiences. If digital stories are too long, they can become boring and impede children's concrete experiences. For this reason, three to five minutes is a sufficient length for digital math stories. The completed digital math stories can be subjected to a trial run with one or two children and updated according to their views before sharing the digital stories with the whole group.
7. **Sharing the story**: The final structure of the story is revealed by evaluating the sound, image, and content. The characteristics of the story and the audience are reviewed. The audience for the story is determined by deciding whether the story will be shared individually, in a group, and directly or indirectly (Lambert, 2013). In this step, the educator shares their completed digital mathematics story with their intended audience. This audience can be children and parents or child-specific. The digital story can even be shared on social media (Kearney, 2011). Sharing digital stories allows educators to gain insights into children's

learning (Kervin & Mantei, 2016). It allows them to express their own experiences, perceptions, and dreams while sharing the digital story and interacting with the child. Digital stories voice mathematical problems and apply different perspectives to them, thus increasing children's motivation for learning. While the children are watching the digital stories, the teacher observes the children and records their impressions. These recordings form the basis for tracking the children's math skills and determining the content of the next digital math stories.

After the steps of digital storytelling were a story titled "Address" and created with Microsoft Photos was presented (Appendix), drawing on insights from Lambert (2013). This story was analyzed with the seven steps of digital storytelling and accompanied by a description of the technical commands that were used in its creation. Finally, teachers followed seven steps to create digital mathematics stories on the computer, assisted by individual guidance.

## 17.3 Results

In this study, which aims to integrate digital storytelling in mathematics education, theoretical and practical training was provided for seven days to encourage teachers to create digital mathematics stories. Teachers expressed the limitations of their digital skills at the beginning of the training and stated that they were concerned they would be unable to construct a digital math story. However, as a result of the individual guidance and positive motivation provided during the training, and the teachers' desire to learn, each teacher created an average of three digital mathematics stories. At the end of the study, interviews with each teacher revealed that the Digital Mathematics Stories Training contributed to their self-confidence, ability to use different programs, creative thinking, digital skills, and understanding of the relationship between mathematics and digital storytelling.

***Self-confidence***: While the teachers were not troubled by their minimal knowledge of technology integration and limited technology skills, they stated that their self-confidence increased after the Digital Mathematics Stories Training. In addition, they expressed that they would continue to improve their skills and apply this method in their classrooms. For example, T20 expressed her self-confidence development as follows: "I came in scared, now I'm leaving with more confidence. In fact, many of my teacher friends couldn't even apply when that technology went digital. We were a little braver, but we are still a group with fears. Again, because we are not in full control. In this sense, even with my friends who never participated, there were advances in mathematics, digital was not that difficult, you could do it from here, it was a program, in fact, we could do it too… Even now, when I enter YouTube, when I see the animated characters there, I say this is it. I say that I could have done much better, it used to be a very scary thing, frankly, preparing it."

T4 shared a similar statement: “I can do it myself. I can implement it in my own class. I can share it with my friends. It showed its applicability in daily life. It showed that we can take the concepts from daily life in the form of a story and give them to children easily.” Thus, teachers gained self-confidence in being able to create a compelling digital story without supervision.

***Learning to use different programs***: During the Digital Mathematics Stories Training, teachers created stories with multiple applications. Microsoft Photos, Moovly, Canva, and Story board were among these programs. Thus, the training was intended to improve teachers’ digital story creation skills with various techniques and approaches. It was observed that the teachers had difficulty timing the motion and sound recordings during the practice sessions, and these struggles were addressed with individual guidance. T12 expressed her achievement during the one-week training by saying, “If you had asked me to prepare a digital story a week ago, it would have been a classic PowerPoint presentation, so now I learned three or four programs. I thought I used Canva last year, I thought I didn’t just we were making collages there, frankly, I didn’t reach that many varieties of visual, video and sound seriously. I have had gains. 10% said that my knowledge and competency about digital and I think that this has increased to 60–70%.”

T11 stated that the programs and practices she learned were superior to the previous programs she used: “I prepared digital material before. Especially during the distance education process, when making conversations with children through Zoom. But they were simpler things. Like Wordwall for example. I don’t remember the others at the moment, we had prepared an event with them, but this is more professional and nicer.”

***Creativity and productivity***: In the Digital Mathematics Stories Training, teachers were involved in two separate creativity exercises. First of all, they wrote the content of their mathematics stories to address the mathematics needs they observed in their students. Then, in accordance with this text, they turned to digital design and chose visual, audible, and animated features that would attract children’s attention. T13 explained that her creativity and productivity increased: “I started to think more creatively about math stories. Since I strain my brain in this regard, I think that when I work on any concept in my class, I can play it with children, dramatize it, and turn it into a digital story. There are many different things in my mind about children. For example, by making my students characters and using their pictures, stories are family participation studies for them, and stories that they can design by informing their families. Many different things have occurred in my head.”

T5, on the other hand, stated that she advanced from using ready-made materials to producing her own materials: “I wasn’t preparing a lot of digital materials, we were using ready-made puzzles and stuff. Now that I will produce it myself, it has completely provided this. I was using ready-made programs, I can prepare it myself, now I can say that added it.”

***Developing their digital skills***: The practical portion of the training was structured so that teachers had the opportunity to develop their existing digital skills by receiving individual instruction as they worked with digital programs. T20 described how this experience equipped her with new skills: "I could never use ready-made digital content in this area. Either the sound was too bad, the image was too bad, or it was foreign, not suitable for the class. If I lowered his voice, I couldn't accompany him, but now I can shape it under my control, and I can actively create content according to the child's needs and individuality."

***Better understanding of the relationship between mathematics and digital storytelling***: Teachers created mathematics stories according to the mathematics needs they observed in children and transferred these stories to digital media. Even for teachers with a minimal understanding of the relationship between mathematics and technology, this application produced concrete results. For example, T14 stated that she became aware of the feasibility of mathematics education in the digital environment: "I could think very little about mathematics education in the digital environment, I was preparing more concrete games, I saw that I could also be given digitally. I thought it wouldn't be digital." T11 said, "Mathematics always intimidates people. In fact, this can be taught very easily and fun, or rather, technology is already very advanced today. Children all use tablets, computers, smartphones. I think they can love mathematics more by developing digital content." She appreciated how digital stories can encourage a love for mathematics in children.

T5 stated that the Digital Mathematics Stories Training gave her ideas to create stories about different concepts: "I never used to narrate mathematical concepts other than numbers. ….I did not know how to produce a story with mathematics, or rather, I did not use it, it was not a method that came to my mind now, I am thinking of using it now, it is about the other concepts I will teach." Teachers also stated that they used various applications in the integration of mathematics and technology but that they preferred to use digital stories in their classrooms after completing the Digital Mathematics Stories Training.

## 17.4 Discussion

The pandemic has brought the need for teachers to possess digital competence to the forefront of discussions. In addition, although it may seem easy to access digital education materials, these materials are primarily produced for commercial purposes. Therefore, the challenge of adapting these materials for children's education is another issue. On top of these rich stimulus conditions, there are individual differences in learning, and the need for teachers to design mathematics materials suitable for their students will never lose its importance. Today's technology offers teachers the option to not only use existing materials, but also to produce their own media. Moreover, digital storytelling is an ideal teaching method for teachers given its ease of preparation, affordability, and multidimensionality. In this study, Digital Mathematics Stories Training provided teachers with the opportunity to both improve their digital skills and integrate digital storytelling into mathematics education. Considering the wealth of concepts in mathematics, digital storytelling is an optimal method of communicating content.

Research findings indicated that Digital Mathematics Stories Training contributed to teachers' self-confidence, creative thinking, learning to use different programs, improving their digital skills, and better understanding the relationship between mathematics and technology. The training consisted of theoretical lessons and practical application. Although the training period was limited to seven days due to the project funding, teachers received one-on-one instruction and a total of 56 h of training that increased their development.

The principal finding of the study was that the Digital Mathematics Stories Training resulted in an increase in the teachers' awareness of digital storytelling and their ability to integrate digital storytelling into mathematics education. In a similar study, Starčič et al. (2016) found that digital story training contributed to the pedagogical competencies and mathematical content knowledge of the participants in their study with pre-service teachers. Sancar-Tokmak and Incikabı (2013) also provided teacher candidates with technological guidance on how to create a digital story. They concluded that digital storytelling is a useful tool in early childhood mathematics education. Furthermore, when teachers learn digital storytelling, they recognize its benefits and demonstrate a willingness to apply it in their classrooms and facilitate effective learning (Sadik, 2008; Undheim & Jernes, 2020; Yuksel Arslan et al., 2016).

After completing the Digital Mathematics Stories Training, teachers experienced a shift in their approach to integrating mathematics and technology. They stated that although they used various applications in the integration of mathematics and technology, the training caused them to prefer digital stories. It is noteworthy that many studies on the integration of technology in classroom mathematics education include the use of applications (Cary et al., 2020; Genç et al., 2020; Kermani, 2017; Outhwaite et al., 2017, 2019; Verbruggen et al, 2021; Zaranis et al., 2013). In particular, it is stated in some studies that meaningful math experiences on the touch screen cause a significant increase in children's mathematical skills (Papadakis et al., 2016, 2021). Compared to other digital applications digital stories prepared by the teacher will contribute to the introduction, reinforcement, and internalization of mathematical concepts specifically for the child. NCTM (1989) stated that mathematics stories are an effective way to introduce mathematical ideas since they present mathematical concepts to children in a meaningful context. Rahiem (2021) postulated that teachers prefer technology because it makes storytelling more entertaining and engaging. In addition, the unlimited design elements of digital stories allow a new story to be prepared for each mathematical concept and skill. Digital stories therefore enable children to progress to more content and are a powerful learning tool for mathematics and critical thinking skills. The concepts of mathematics can also be enhanced with sounds, effects, music, movements, symbols, drawings, and pictures.

The study has revealed that after completing the training, teachers were amazed to find they had transformed their limited digital competencies into advanced skills. Their digital anxieties turned into productivity and self-confidence. The relationship between teachers' pedagogical beliefs and technology beliefs is decisive in integrating digital technologies into children's learning (Vidal-Hall et al., 2020). Jo (2016) indicate that digital activities had a positive impact on preserve teachers' beliefs, attitudes, and confidence in implementation and teaching spatial thinking in their future classrooms. Thang et al. (2014) suggested several recommendations to both avoid failure and encourage teachers to adopt a positive attitude toward technology, such as assisting the pedagogical use of technology, involving teachers in activity planning, recognizing teachers' successes, and promoting collaboration between teachers. These strategies informed the Digital Mathematics Stories Training, in which teachers received individual guidance, experienced motivational learning exercises, and were prompted to interact with their colleagues. While the teachers created stories, they discussed what they learned from the educators with their colleagues and increased each other's motivation. The results of this study were drawn from the interview records obtained during the training. In addition, the study was based only on teaching educators about digital storytelling and equipping them with the skills to create digital stories. Undheim and Jernes (2020) states that when teachers involve children in the production of digital storytelling, they experience enjoyable interactions. The short duration of the research project did not make it possible to transfer teachers to children. Further research can be conducted to determine how the teachers adapt their digital mathematics stories to the classroom environment and the reactions of the children.

This study has emerged with the support of TUBITAK and Gazi University. The institutions where the research is carried out also have an important role in the realization of a research and its scientific qualifications (Petousi & Sifaki, 2020). This is inevitable especially in project-based research. In the realization of this project, TUBITAK provided financial support, Gazi University provided space and all physical and motivational support. These contributions both increased the scientific power of the study and increased social gains through the training of teachers. However, due to financial limitations, digital storytelling training is limited to one week. In future studies, the training process can be planned longer, and follow-up studies can be included.

## 17.5 Conclusion

Mathematics is comprised of countless concepts and skills. To promote effective learning, each concept needs to be addressed via a mode that suits children's needs and interests and is associated with their lives. Although it is there are published math materials, very few have proper content and functionality. They rapidly become outdated and are not always suited to the needs of the children and the goals of the curriculum. Digital story creation is therefore a modern alternative that allows teachers to create multiple digital stories that are tailored to their students' needs. Digital stories are easy to prepare and can be created by anyone with little digital literacy, even children, without the need for special skills or extensive training. In this study, which aims to adapt digital storytelling to early mathematics education, teachers were supported to create digital mathematics stories. It has been found that as teachers learn to create digital mathematics stories, they acquire the competencies that they can use in mathematics education for their purposes. When teachers create a digital story for their class, they will experience the satisfaction of using their professional skills effectively while also helping children to learn effectively by presenting stories suitable for children's learning goals in short and practical ways. Children will experience mathematics through a more immersive avenue and learn with more interest and engagement. Nonetheless, digital stories are not meant to be the sole source of information, though they are an effective means of reaching the digital generation. Prior to interacting with digital stories, children will have concrete experiences about mathematical concepts in the educational environment. Supporting this existing learning with digital storytelling will enable them to establish relationships between learning. Yet learning based only on watching these videos will be superficial. Pausing the videos to ask questions and reinforce experiences will enhance interaction and solidify learning. After the digital stories, put the concepts into practice in the classroom. For example, after a story about grouping by category, children can group the blocks according to their colors.

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**Ethics** The research was carried out in accordance with the guidelines published by American Psychology Association's following the general Ethical Principles of Psychologists and Code of Conduct principles (2002). The ethical approval from the Ethical Commission of Gazi University was provided before the research. Teachers were informed with the details of the study and that participation was voluntary at their consent.

# Appendix



Narrater: "One day, the Mole thought that he had never visited his friend turtle, who was in another part of the forest"
Sound: Mole sound
Speech: Shown in Scene 1. Mole thought bubble

Narrater: "He took the address card and set off. He read the address and walked through the narrow road. But the road splits in two there. He looked at the address again. The mole paused and looked around, because he was confusing his right and left and he did not know which way to go."
Speech: Mole thought bubbles (left to right)



Sound: Squirrel sound. Then the speech starts.
Speech: Shown in the scene 3. First squirrel asks then the mole replies.

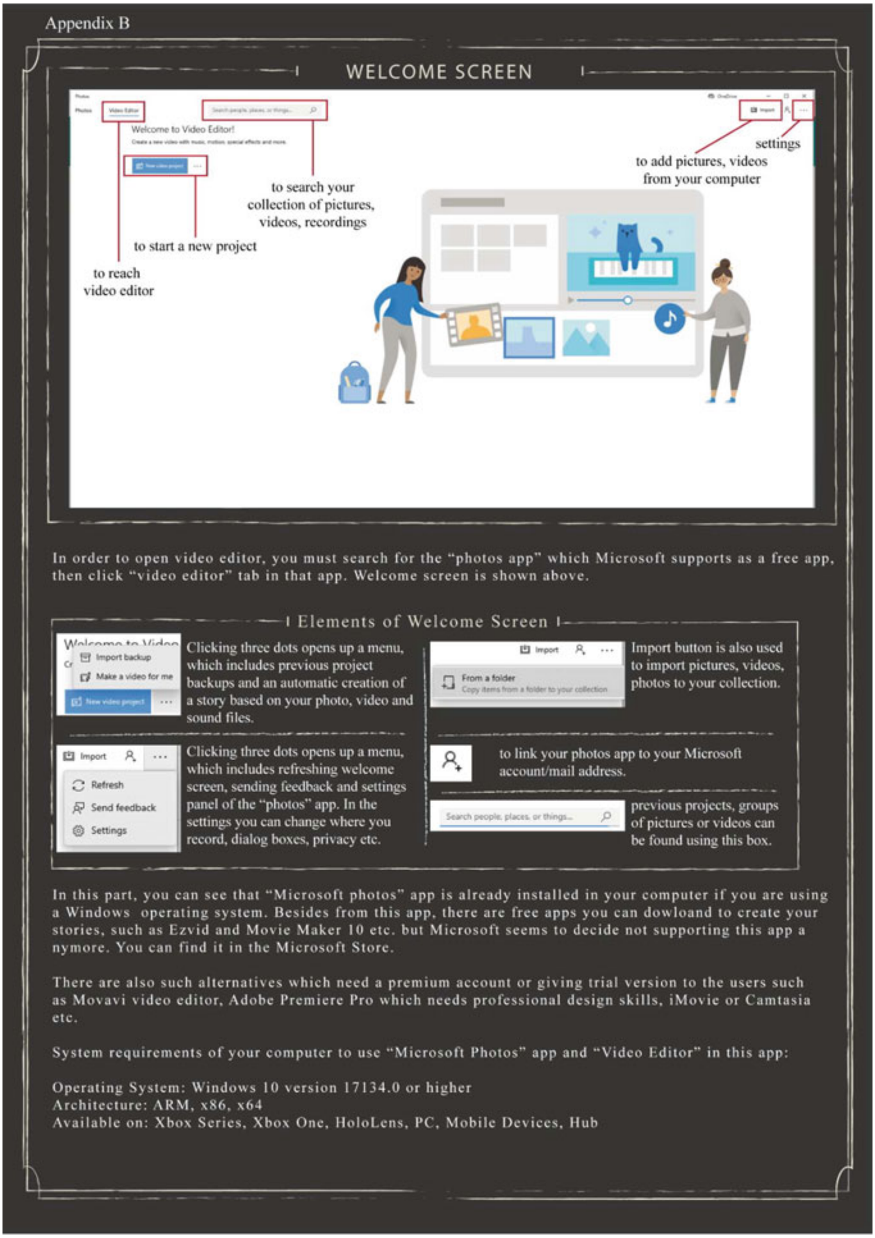
Speeches:
The Squirrel: Put the leaf in your left pocket
the left on your hand.
The Squirrel: The left on the plane three leaf
Remind this leaf as you turn left
The Mole: Thank you for your help, I will continue
on this path
The Squirrel: Goodbye, my friend goodby.
When you find your friend say Hi

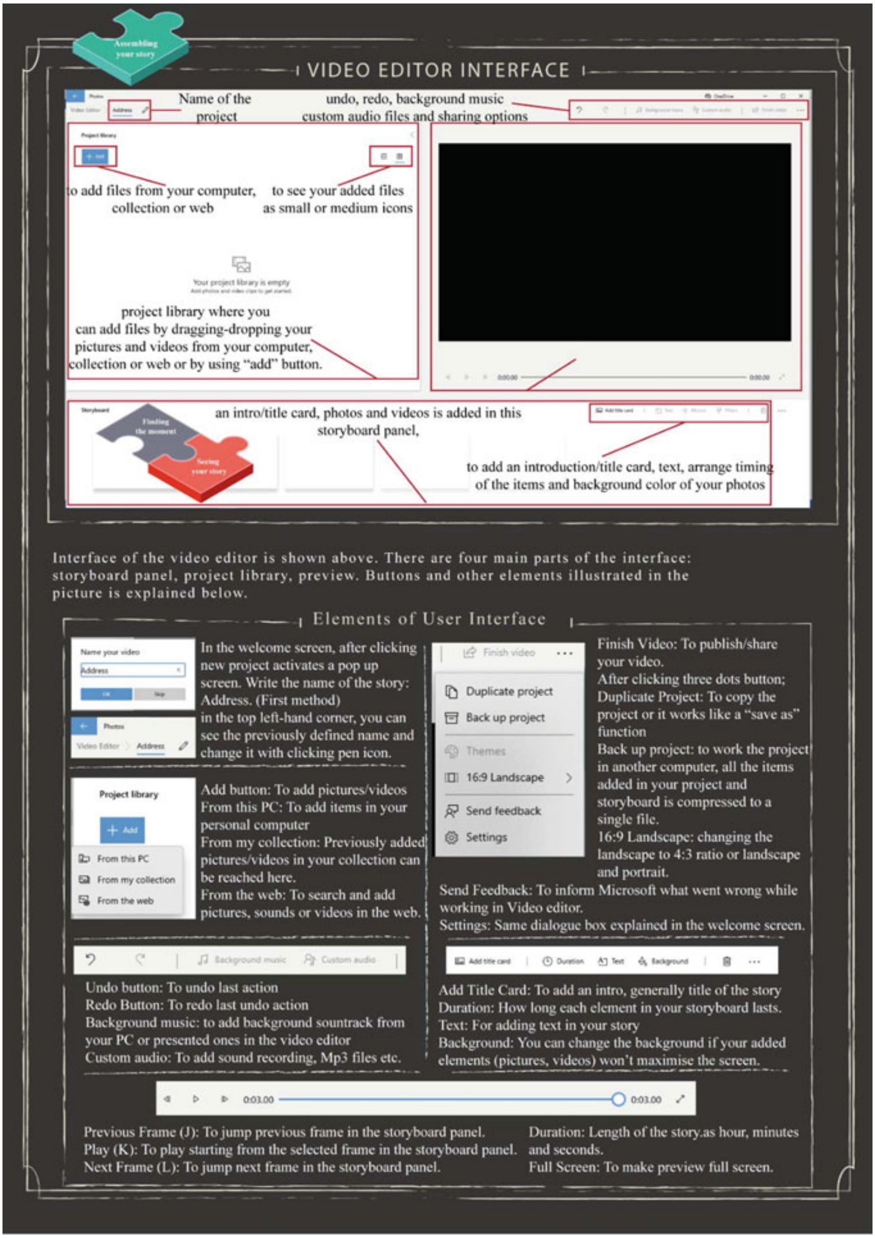

Narrater: "The Mole came to the end of the road, he read the address paper again. Again which is left which is right? The mole remembered the squirrel and the leaf on the left pocket. He checked the "L" on his left hand and the leaf on his left pocket.
Speech: Mole says "You will see a bridge at the end of the road. Cross the bridge and count five houses on the right" and yes, this is left, and this is right

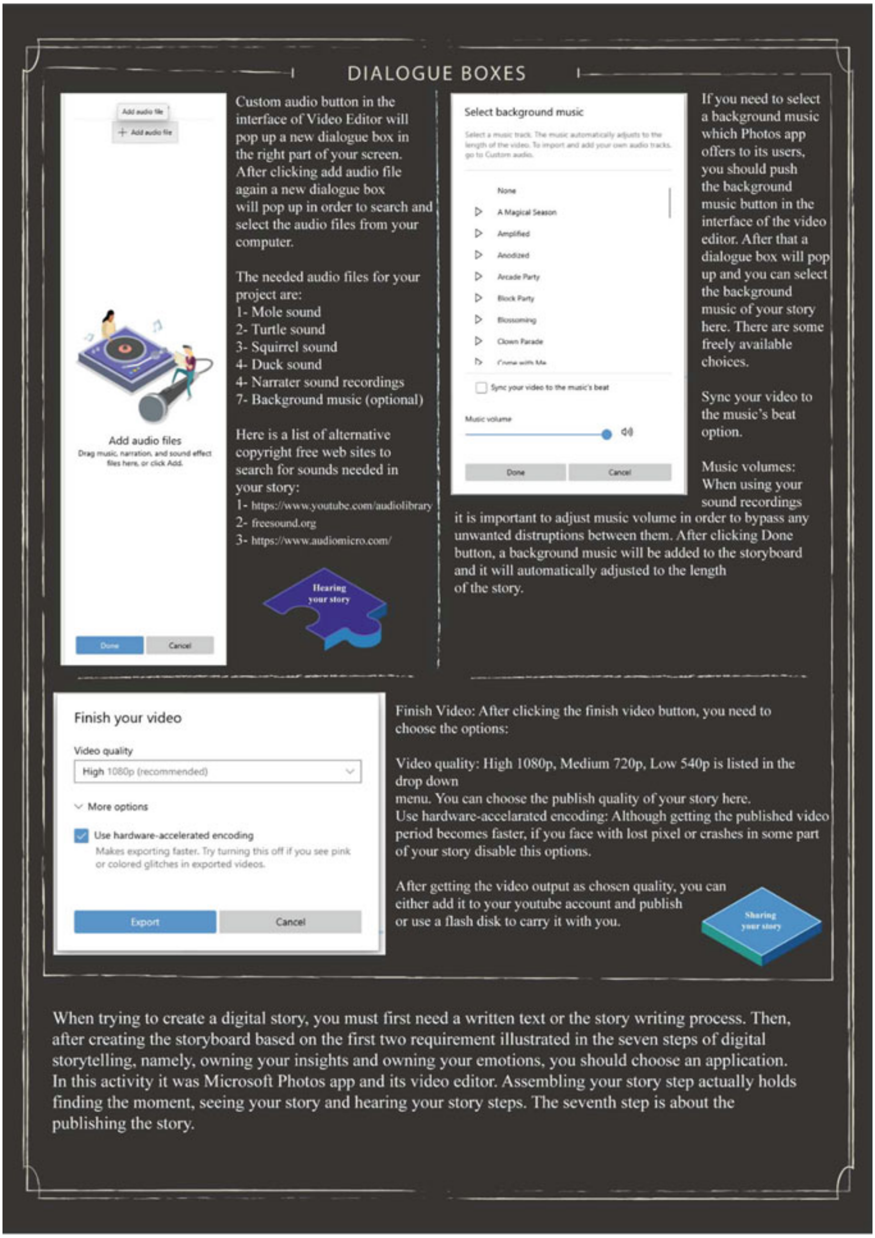

Narrater: "The Mole crossed the bridge and counted five house on the right and rang the bell of house number five."
Speech: Mole thinks " My house is number five at the corner that comes after counting five houses."
Mole says "One, two, three, four and five"


Narrater: "A white fluffy duck opened the door. The mole asked his friend."
Sound: Duck sound.
Speech: The Duck: Hi, can I help you?
The Mole: I am the friend of the turtle, I came to visit him, he gave me the address of this house, does he live here?
The Duck: The tortoise does not live here, it has moved to the house number one at the corner,
Narrater: "He thanked the Duck and started to find the house number one."


Narrater: "He went on the road"
Speech: Mole says "House number four, house number three, house number two, house number one, yes here."
Narrater: "He rang the bell with great enthusiasm. The turtle opene the door and was very surprised"
Turtle says "yuppie, well come"


Appendix B
WELCOME SCREEN
Welcome to Video Editor!
settings
to add pictures, videos from your computer
to search your collection of pictures, videos, recordings
to start a new project
to reach video editor
In order to open video editor, you must search for the "photos app" which Microsoft supports as a free app, then click "video editor" tab in that app. Welcome screen is shown above.
Elements of Welcome Screen
Import backup
Make a video for me
New video project
Clicking three dots opens up a menu, which includes previous project backups and an automatic creation of a story based on your photo, video and sound files.
Import
From a folder
Copy items from a folder to your collection
Import button is also used to import pictures, videos, photos to your collection.
Import
Refresh
Send feedback
Settings
Clicking three dots opens up a menu, which includes refreshing welcome screen, sending feedback and settings panel of the "photos" app. In the settings you can change where you record, dialog boxes, privacy etc.
to link your photos app to your Microsoft account/mail address.
Search people, places, or things...
previous projects, groups of pictures or videos can be found using this box.
In this part, you can see that "Microsoft photos" app is already installed in your computer if you are using a Windows operating system. Besides from this app, there are free apps you can dowload to create your stories, such as Ezvid and Movie Maker 10 etc. but Microsoft seems to decide not supporting this app a nymore. You can find it in the Microsoft Store.
There are also such alternatives which need a premium account or giving trial version to the users such as Movavi video editor, Adobe Premiere Pro which needs professional design skills, iMovie or Camtasia etc.
System requirements of your computer to use "Microsoft Photos" app and "Video Editor" in this app:
Operating System: Windows 10 version 17134.0 or higher
Architecture: ARM, x86, x64
Available on: Xbox Series, Xbox One, HoloLens, PC, Mobile Devices, Hub


Assembling your story
VIDEO EDITOR INTERFACE
Name of the project
undo, redo, background music custom audio files and sharing options
to add files from your computer, collection or web
to see your added files as small or medium icons
Your project library is empty
project library where you can add files by dragging-dropping your pictures and videos from your computer, collection or web or by using "add" button.
Finding the moment
Seeing your story
an intro/title card, photos and videos is added in this storyboard panel,
to add an introduction/title card, text, arrange timing of the items and background color of your photos
Interface of the video editor is shown above. There are four main parts of the interface: storyboard panel, project library, preview. Buttons and other elements illustrated in the picture is explained below.
Elements of User Interface
Name your video
Address
In the welcome screen, after clicking new project activates a pop up screen. Write the name of the story: Address. (First method)
in the top left-hand corner, you can see the previously defined name and change it with clicking pen icon.
Photos
Video Editor
Address
Project library
+ Add
From this PC
From my collection
From the web
Add button: To add pictures/videos
From this PC: To add items in your personal computer
From my collection: Previously added pictures/videos in your collection can be reached here.
From the web: To search and add pictures, sounds or videos in the web.
Finish video
Duplicate project
Back up project
Themes
16:9 Landscape
Send feedback
Settings
Finish Video: To publish/share your video.
After clicking three dots button;
Duplicate Project: To copy the project or it works like a "save as" function
Back up project: to work the project in another computer, all the items added in your project and storyboard is compressed to a single file.
16:9 Landscape: changing the landscape to 4:3 ratio or landscape and portrait.
Send Feedback: To inform Microsoft what went wrong while working in Video editor.
Settings: Same dialogue box explained in the welcome screen.
Background music
Custom audio
Undo button: To undo last action
Redo Button: To redo last undo action
Background music: to add background sountrack from your PC or presented ones in the video editor
Custom audio: To add sound recording, Mp3 files etc.
Add title card
Duration
Text
Background
Add Title Card: To add an intro, generally title of the story
Duration: How long each element in your storyboard lasts.
Text: For adding text in your story
Background: You can change the background if your added elements (pictures, videos) won't maximise the screen.
0:03.00
0:03.00
Previous Frame (J): To jump previous frame in the storyboard panel.
Play (K): To play starting from the selected frame in the storyboard panel.
Next Frame (L): To jump next frame in the storyboard panel.
Duration: Length of the story.as hour, minutes and seconds.
Full Screen: To make preview full screen.


DIALOGUE BOXES
Add audio file
Add audio file
Add audio files
Drag music, narration, and sound effect files here, or click Add.
Done
Cancel
Custom audio button in the interface of Video Editor will pop up a new dialogue box in the right part of your screen. After clicking add audio file again a new dialogue box will pop up in order to search and select the audio files from your computer.
The needed audio files for your project are:
1- Mole sound
2- Turtle sound
3- Squirrel sound
4- Duck sound
4- Narrater sound recordings
7- Background music (optional)
Here is a list of alternative copyright free web sites to search for sounds needed in your story:
1- https://www.youtube.com/audiolibrary
2- freesound.org
3- https://www.audiomicro.com/
Hearing your story
Select background music
Select a music track. The music automatically adjusts to the length of the video. To import and add your own audio tracks, go to Custom audio.
None
A Magical Season
Amplified
Anodized
Arcade Party
Block Party
Blossoming
Clown Parade
Sync your video to the music's beat
Music volume
Done
Cancel
If you need to select a background music which Photos app offers to its users, you should push the background music button in the interface of the video editor. After that a dialogue box will pop up and you can select the background music of your story here. There are some freely available choices.
Sync your video to the music's beat option.
Music volumes: When using your sound recordings it is important to adjust music volume in order to bypass any unwanted distruptions between them. After clicking Done button, a background music will be added to the storyboard and it will automatically adjusted to the length of the story.
Finish your video
Video quality
High 1080p (recommended)
More options
Use hardware-accelerated encoding
Makes exporting faster. Try turning this off if you see pink or colored glitches in exported videos.
Export
Cancel
Finish Video: After clicking the finish video button, you need to choose the options:
Video quality: High 1080p, Medium 720p, Low 540p is listed in the drop down menu. You can choose the publish quality of your story here.
Use hardware-accelarated encoding: Although getting the published video period becomes faster, if you face with lost pixel or crashes in some part of your story disable this options.
After getting the video output as chosen quality, you can either add it to your youtube account and publish or use a flash disk to carry it with you.
Sharing your story
When trying to create a digital story, you must first need a written text or the story writing process. Then, after creating the storyboard based on the first two requirement illustrated in the seven steps of digital storytelling, namely, owning your insights and owning your emotions, you should choose an application. In this activity it was Microsoft Photos app and its video editor. Assembling your story step actually holds finding the moment, seeing your story and hearing your story steps. The seventh step is about the publishing the story.

## References


Agélii Genlott, A., & Grönlund, A. (2013). Improving literacy skills through learning reading by writing: The iWTR method presented and tested. *Computers & Education, 67*, 98–104.

Azizah, C. N., Mutalib, A. A., Aziz, N., & Bakar, R. M. A. (2011). Multiple intelligence ensures the usability of digital storytelling for preschool children. *International Journal on Advanced Science Engineering and Information Technology, 1*(2), 117–123.

Barret, H. C. (2006). Researching and evaluating digital storytelling as a deep learning tool. In C. Crawford, R. Carlsen, K. McFerrin, J. Price, R. Weber, & D. Willis (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2006* (pp. 647–654). Association for the Advancement of Computing in Education (AACE).

Bedir Erişti, S. D. (2017). Technology-focused visual communication and digital storytelling as a dynamic visual communication path for children. *Istanbul University Faculty of Communication Journal, 52*, 25–38.

Bratitsis, T., Kotopoulos, T., & Mandila, K. (2012). Kindergarten children's motivation and collaboration being triggered via computers while creating digital stories: A case study. *International Journal of Knowledge and Learning, 3*, *8*(3–4), 239–258.

Cary, M. S., Kennedy, P. C., Shanley, L., & Clarke, B. (2020). Learning gains from the KinderTEK® iPad math program: Does timing of a preventative intervention matter? *Journal of Special Education Technology*. https://doi.org/10.1177/0162643420928336

Çıralı Sarıca, H. (2019). *Teachers' professional self-understanding and ıts reception by prospective teachers through digital storytelling* (Unpublished doctoral thesis), Hacettepe University.

Clarke, R., & Adam, A. (2011). Digital storytelling in Australia: Academic perspectives and reflections. *Arts and Humanities in Higher Education, 11*(1–2), 157–176.

Couse, L. J., & Chen, D. W. (2010). A tablet computer for young children? Exploring its viability for early childhood education. *Journal of Research on Technology in Education, 43*(1), 75–96.

Dogan, B., & Robin, B. R. (2008). Implementation of digital storytelling in the classroom by teachers trained in a digital storytelling workshop. In K. McFerrin, R. Weber, R. Carlsen, & D. A. Willis (Eds.), *Society for Information Technology & Teacher Education International Conference* (pp. 902–907). Association for the Advancement of Computing in Education (AACE).

Dreon, O., Kerper, R. M., & Landis, J. (2011). Digital storytelling: A tool for teaching and learning in the YouTube generation. *Middle School Journal, 42*(5), 4–10.

Foley, L. M. (2013). *Digital storytelling in primary-grade classrooms* (Unpublished doctoral thesis), Arizona State University.

Frazel, M. (2010). *Digital storytelling guide for educators.* International Society for Technology in Education.

Genç, H., Dağlıoğlu, H. E., & Dağlı, H. (2020). Examining digital games in Google Play Store and Apple Store in terms of mathematics education standards and child appropriateness. *TURAN-SAM, 12*(47), 163–176.

Gözen, G., & Cırık, I. (2017). Impact of digital storytelling on social-emotional behaviours of preschool children. *Elementary Education Online, 16*(4), 18821896.

Hartley, J. & McWilliam, K. (Eds.). (2009). *Story circle: Digital storytelling around the world*. Wiley Blackwell.

Heo, M. (2009). Digital storytelling: An empirical study of the impact of digital storytelling on pre-service teachers' self-efficacy and dispositions towards educational technology. *Journal of Educational Multimedia and Hypermedia, 18*(4), 405–428. http://editlib.org/p/30458/

Hofer, M., & Swan, K. O. (2006, March). Digital storytelling: Moving from promise to practice. In K. McFerrin, R. Weber, R. Carlsen, & D. A. Willis (Eds.), *Society for Information Technology & Teacher Education International Conference* (pp. 679–684). Association for the Advancement of Computing in Education (AACE).

Jo, I. (2016). Future teachers' dispositions toward teaching with geospatial technologies. *Contemporary Issues in Technology and Teacher Education, 16*(3), 310–327.

Kearney, M. (2011). A learning design for student-generated digital storytelling. *Learning, Media and Technology, 36*(2), 169–188.

Kermani, H. (2017). Computer mathematics games and conditions for enhancing young children's learning of number sense. *Malaysian Journal of Learning and Instruction, 14*(2), 23–57. http://doi.org/10.32890/mjli2017.14.2.2

Kervin, L., & Mantei, J. (2016). Digital writing practices: A close look at one grade three author. *Literacy, 50*(3), 133–140.

Kocaman-Karoğlu, A. (2016). Teachers' opinions about digital storytelling in preschool education. *Turkish Online Journal of Qualitative Inquiry, 7*(1), 175–205.

Korosidou, E., & Griva, E. (2020). Digital storytelling in the foreign language classroom: Exploring opportunities for developing multiliteracies in preschool settings. In I. Papadopoulos, E. Griva, & E. Theodotou (Eds.), *International perspectives on creativity in the foreign language classrooms.* NovaScience.

Lambert, J. (2013). *Digital storytelling: Capturing lives, creating community* (4th ed.). Routledge.

Maureen, I. Y., Van der Meij, H., & De Jong, T. (2018). Supporting literacy and digital literacy development in early childhood education using storytelling activities. *IJEC, 50*, 371–389. https://doi.org/10.1007/s13158-018-0230-z

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32*(1), 1–19.

McManis, L. D., & Gunnewig, S. B. (2012). Finding the education in educational technology with early learners. *Young Children, 67*(3), 14–24.

Merjovaara, O., Nousiainen, T., Turja, L., & Isotalo, S. (2020). Digital stories with children: Examining digital storytelling as a pedagogical process in ECEC. *Journal of Early Childhood Education Research, 9*(1), 99–123.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

National Council of Teachers of Mathematics (NCTM). (1989). *Curriculum and evaluation for school mathematics.* NCTM.

Niemi, H., & Multisilta, J. (2016). Digital storytelling promoting twenty-first-century skills and student engagement. *Technology, Pedagogy, and Education, 25*(4), 451–468.

Normann, A. (2011). *Digital storytelling in second language learning: A qualitative study on students' reflections on potentials for learning* (Unpublished master's thesis), Norges teknisk-naturvitenskapelige Universitet.

O'Byrne, W. I., Houser, K., Stone, R., & White, M. (2018). Digital storytelling in early childhood: Student illustrations shaping social interactions. *Frontiers in Psychology, 9*, 1800.

Outhwaite, L. A., Faulder, M., Gulliford, A., & Pitchford, N. J. (2019). Raising early achievement in math with interactive apps: A randomized control trial. *Journal of Educational Psychology, 111*(2), 284–298.

Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2017). Closing the gap: Efficacy of a tablet intervention to support the development of early mathematical skills in UK primary school children. *Computers & Education, 108*, 43–58. https://doi.org/10.1016/j.compedu.2017.01.011

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016). Comparing tablets and PCs in teaching mathematics: An attempt to improve mathematics competence in early childhood education. *Preschool and Primary Education*, *4*(2), 241. http://doi.org/10.12681/ppej.8779

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2021). Teaching mathematics with mobile devices and the Realistic Mathematical Education (RME) approach in kindergarten. *Advances in Mobile Learning Educational Research, 1*(1), 5–18.

Petousi, V., & Sifaki, E. (2020). Contextualizing harm in the framework of research misconduct. Findings from a discourse analysis of scientific publications. *International Journal of Sustainable Development, 23*(3/4), 149–174.

Preradovic, N. M., Lesin, G., & Boras, D. (2016). Introduction of digital storytelling in preschool education: A case study from Croatia. *Digital Education Review, 30*, 94–105.

Rahiem, M. D. H. (2021). Storytelling in early childhood education: Time to go digital. *International Journal of Child Care and Education Policy, 15*(1). https://doi.org/10.1186/s40723-021-00081-x

Robin, B. R. (2006). The educational uses of digital storytelling. In C. M. Crawford, R. Carlsen, K. McFerrin, J. Price, R. Weber, & D. A. Willis (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2006* (pp. 709–716). AACE.

Robin, B. R. (2008). Digital storytelling: A powerful technology tool for the 21st century classroom. *Theory into Practice, 47*, 220–228.

Sadik, A. (2008). Digital storytelling: A meaningful technology-integrated approach for engaged student learning. *Educational Technology Research and Development, 56*(4), 487–506.

Sancar-Tokmak, H., & Incikabi, L. (2013). The effect of expertise-based training on the quality of digital stories created to teach mathematics to young children. *Educational Media International, 50*(4), 325–340. https://doi.org/10.1080/09523987.2013.863469

Starčič, A. I., Cotic, M., Solomonides, I., & Volk, M. (2016). Engaging preservice primary and preprimary school teachers in digital storytelling for the teaching and learning of mathematics. *British Journal of Educational Technology, 47*(1), 29–50. https://doi.org/10.1111/bjet.12253

Technological Pedagogical Content Knowledge/TPACK. (2012). What is TPACK. http://tpack.org

Tendero, A. (2006). Facing your selves: The effects of digital storytelling on teacher education. *Contemporary Issues in Technology and Teacher Education, 6*(2), 174–194.

Thang, S. M., Lin, L. K., Mahmud, N., Ismail, K., & Zabidi, N. A. (2014). Technology integration in the form of digital storytelling: Mapping the concerns of four Malaysian ESL instructors. *Computer Assisted Language Learning, 27*(4), 311–329. https://doi.org/10.1080/09588221.2014.903979

Toki, E. I., & Pange, J. (2014). ICT use in early childhood education: Storytelling. *Tiltai, 66*(1), 183–192.

Towndrow, P. A., & Kogut, G. (2020). Conclusion. Digital storytelling in classrooms. In *Digital storytelling for educative purposes* (pp. 147–168). Springer.

Tzima, S., Styliaras, G., Bassounas, A., & Tzima, M. (2020). Harnessing the potential of storytelling and mobile technology in intangible cultural heritage: A case study in early childhood education in sustainability. *Sustainability, 12*(22), 9416.

Undheim, M., & Jernes, M. (2020). Teachers' pedagogical strategies when creating digital stories with young children. *European Early Childhood Education Research Journal, 28*(2), 256–271. https://doi.org/10.1080/1350293X.2020.1735743

Verbruggen, S., Depaepe, F., & Torbeyns, J. (2021). Effectiveness of educational technology in early mathematics education: A systematic literature review. *International Journal of Child-Computer Interaction*, *27*, 100220. https://doi.org/10.1016/j.ijcci.2020.100220

Verdugo, D. R., & Belmonte, I. A. (2007). Using digital stories to improve listening comprehension with Spanish young learners of English. *Language Learning & Technology, 11*(1), 87–101.

Vernadakis, N., Avgerinos, A., Tsitskari, E., & Zachopoulou, E. (2005). The use of computer-assisted instruction in preschool education: Making teaching meaningful. *Early Childhood Education Journal, 33*(2), 99–104.

Vidal-Hall, C., Flewitt, R., & Wyse, D. (2020). Early childhood practitioner beliefs about digital media: integrating technology into a child-centred classroom environment. *European Early Childhood Education Research Journal, 28*(2), 167–181. https://doi.org/10.1080/1350293X.2020.1735727

Yang, Y. T. C., & Wu, W. C. I. (2012). Digital storytelling for enhancing student academic achievement, critical thinking, and learning motivation: A year-long experimental study. *Computers & Education, 59*(2), 339–352.

Yuksel-Arslan, P., Yildirim, S., & Robin, B. R. (2016). A phenomenological study: Teachers' experiences of using digital storytelling in early childhood education. *Educational Studies, 42*(5), 427–445.

Zaranis, N., Kalogiannakis, M., & Papadakis, S. (2013). Using mobile devices for teaching realistic mathematics in kindergarten education. *Creative Education, 4*, 1–10.

# Chapter 18
# The Future of Interaction: Augmented Reality, Holography and Artificial Intelligence in Early Childhood Science Education

**Xinyue Li and Keith S. Taber**

**Abstract** There is little doubt that the development of technology has changed the landscape of science learning in both formal and informal settings. However, often existing research studies lack a strong conceptual underpinning in terms of pedagogic theory. Regardless of the fair body of studies relating to early childhood education and science education, early childhood science learning remains a relatively under-researched area. As representatives of advanced technologies which have been widely adopted in many fields, augmented reality (AR), holography and artificial intelligence (AI) have rarely been applied and studied in early childhood science education despite the enormous potential they offer. Drawing upon Vygotsky's notions of the zone of proximal development (ZPD), tools and mediation, this chapter provides a new perspective by exploring the potential use of AR applications (apps), holography and AI-based tools in early childhood science education. The key argument is that these tools can potentially change the nature of the interaction between learners and learning materials, and they offer significant affordances in early childhood science education. The mission of the present chapter is to inform the design and development of educational technology based on psychological and pedagogical perspectives, and help parents and early childhood teachers understand the potential use of AR, holography and AI in science education.

**Keywords** AR in education · AI in education · Holography in education · Zone of proximal development · Scaffolding learning · Mediation

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## 18.1 Introduction

The development and application of educational technology have catalysed profound changes in modes of acquiring and imparting knowledge. Many digital learning and teaching resources, including software and hardware, have been iteratively modified and developed in response to changes in the learning and teaching experience (Mason & Boscolo, 2000; Taber & Li, 2021; Winter et al., 2010). Some traditional tools, including chalkboards, desktop computers and paper textbooks, have largely been superseded by interactive boards, laptops or tablets and digital learning materials (Balanskat, 2013; Clark et al., 2009; Clarke et al., 2013; Schnackenberg, 2013). In addition, many technologies which have been widely used in various fields, including 3D printing, robotics, big data, artificial intelligence (AI), augmented reality (AR), holographic projection, etc., are gradually being made available to learners, parents and educators (Taber & Li, 2021). These tools have demonstrated great potential to assist children in early childhood to learn, especially in science education.

In this chapter, we consider the characteristics of some AR applications (apps), holography and AI-based tools available for children to learn science. These tools would offer sources of knowledge and support the mediation between learners and learning materials. To exemplify this, we focus on AR apps (which are available for smartphones and tablets), the smart lamp, smartphones, tablets, AI-based learning robots and the scanning pen, which have been used by children to learn science in early childhood. We focus on learners up to the age of 8: as we cannot expect them to take major responsibility for their learning, parental guidance is often needed. Therefore, in this chapter, we only focus on tools that are designed for, or have been adopted for, and used by children who undertake science learning in out-of-class contexts, either with or without parental guidance (in the case of older learners). The devices which are intended for use by professional institutions (e.g. museums) are not discussed.

## 18.2 A Programme for the Chapter

This chapter presents a possible vision for and proposal of how the technologies of AR, holography and AI will reshape the landscape of early childhood science education in terms of the interaction between learners and learning materials. It begins by reporting a brief review of literature on Vygotsky's notions of the zone of proximal development (ZPD) and scaffolding (Taber, 2020; Taber & Li, 2021; Vygotsky, 1978). Next, we discuss how the construction of knowledge can be developed in the ZPD through scaffolding. We then consider the implications of Piaget's work in his programme of genetic epistemology (Piaget, 1932/1977, 1970/1972).

It has been argued that there is a lack of explaining technology theoretically in the research literature (Oliver, 2013). Therefore, we describe and characterise some of the popular tools available in early childhood science education, providing readers with a general overview of the background of the present chapter. In particular, we consider the use of AR apps, holography and AI-based tools outside of the classroom, either under parental guidance or by children themselves in self-directed learning. Because it can be challenging for young learners with limited understanding and knowledge to identify the reliability of tools that they use for learning, this raises the question of how AR apps, holography and AI-based tools can be designed and used to mediate productive learning experiences in children's ZPD. This leads us to explore:

- What are the features of resources that can offer experiences to make otherwise abstract ideas seem more concrete?
- What are the features of resources that can support young children's learning as mediating tools?
- To what extent do the technologies discussed here currently offer these features?
- How might the technologies be developed to better act as tools to mediate science learning in young children?

These are the objectives and foci of the present chapter. Some of the tools discussed in this chapter are applicable to be used to learn many subjects; we offer some science-specific examples since we focus on early childhood science learning.

Unlike teachers who are more capable of evaluating digital technology critically, parents and children may have a limited basis to choose the most appropriate tools to use, especially when many digital technology companies spend so much budget on marketing and advertising. Therefore, the mission of the present chapter is to analyse some of the popular AR apps, holography and AI-based tools from both practical and theoretical perspectives, and to help inform the design and development of educational technology based on psychological and pedagogical perspectives, and research into the development and employment of such tools. Furthermore, to inform parents and early childhood teachers about the potential applications of AR, holography and AI in science education, we offer a generic account—rather than focusing on any particular context (country or institution), the discussion of this chapter is intended to have general relevance.

## 18.3 Supporting Development: Vygotsky's Notion of ZPD

The Russian psychologist Vygotsky explored the nature of human learning and development, focusing on how culture (which might be thought of as the past learning of a community) is acquired through social mechanisms (Vygotsky, 1978). Vygotsky's ideas have become very influential in education (e.g., Taber, 2020) and are relevant to the uptake of modern digital technologies in learning (Taber & Li, 2021). Vygotsky proposed the idea of the zone of proximal development (ZPD), which refers to the 'distance between the actual development level as determined by independent problem solving and the level of potential development as determined through

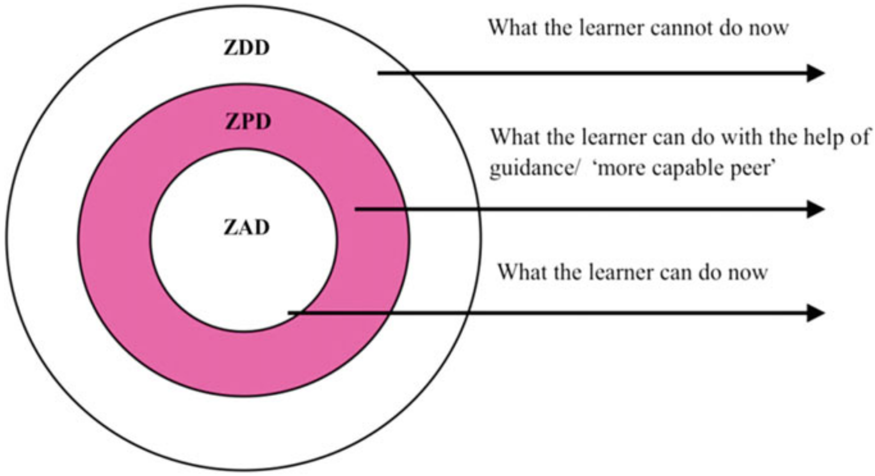


**Fig. 18.1** Representation of the ZPD (Based on Vygotsky's ideas, 1978)

problem-solving under adult guidance or in collaboration with more capable peers' (Vygotsky, 1978: 86). Figure 18.1 represents Vygotsky's model of ZPD.

Working in ZPD aims to develop beyond what the learner has already mastered, including knowledge and skills, with the help of a guide such as a teacher or a 'more capable peer'. The adult or more advanced peer, who has previously been inducted into aspects of culture not yet available to the learner, is able to mediate between the learner and the aspect of culture (here, some knowledge or skills) that is the focus of the learning. This tends to happen by modelling, particularly in carrying out activities that the learners can slowly begin to share. According to Vygotsky, in this way, what is initially experienced vicariously, by engaging with an 'expert', on the social or inter-personal plane is—through the learner's increasing participation—assimilated onto the intra-personal or mental plane. That is, the learner passes through a process from guided participation (where the more expert other directs activity) to a position where the activity can be self-directed. Thus, the activity has shifted from something that the learner could not do to something that they could do via a phase of undertaking the activity with guidance. This is a general model, and can be seen as a description of much human learning that takes place spontaneously—for example, when parents play learning games with their children or when mixed-age groups of children play together. Yet, whilst in that sense, Vygotsky's model can be seen as descriptive, it does not imply that effective learning always occurs when a novice seeks to engage in an activity with a more experienced partner. Such learning can be spontaneous, but is certainly not automatic.

When considered from a pedagogic perspective, Vygotsky's ideas have been understood in terms of how the 'teacher' (whether a professional teacher, or someone such as a parent taking this role in a particular situation) structures the shared activity to best support the learner. In effect this means that there is a kind of staged hand-over.

Initially the 'expert' does everything, and the learner is little more than an observer, but their involvement (and responsibility) is slowly increased. The term scaffolding is applied to the structuring of activity so that the learner is able to engage in aspects of the activity meaningfully whilst the overall organisation of the process is managed for them. As the learner develops familiarity and skill (or understanding), the scaffolding is 'faded', that is incrementally dismantled, so that eventually the learner has a mastery (Taber, 2018). This clearly requires considerable skill, or luck, in removing support at the right rate. If scaffolding is dismantled too slowly, then development will be suboptimal, the challenge will be low, and interest may be lost. If scaffolding is removed too quickly, then failure and frustration are more likely. This sets a high bar for the teacher's skills, but in the context of participation in shared activities, the teacher gets continuous feedback from the learner, which allows adjustments to be made. In a dyad of a more experienced and a less experienced child, such a sufficiently effective process for learning can occur, not because the older child has any formal pedagogic expertise, but simply because the older child may be sufficiently sensitive to the less experienced child's need for support.

Scaffolding is a challenging technique to finesse (Taber & Brock, 2018), but humans with empathy still often manage to teach others through shared engagement in activities. The process will usually be far from optimal in the sense that learning to play marbles, to read, to sew, or whatever, through these spontaneous social interactions may rely on extended engagement in an activity that is a strong focus of the social group (Piaget, 1932, 1977)—and so a time commitment that would rarely be available in a formal educational context with a packed curriculum. Before considering the specific focus of the present chapter, it is useful to develop this model in two regards. The first of these concerns is Vygotsky's strong focus on tools that can support learning and development.

## 18.4 Tools and Mediation

Vygotsky proposed that Tools serve the 'mediating role in human reaction and interaction with the world' (Verenikina, 2010: 19). However, the canon of many research studies in the field of educational technology 'makes many claims about technology's effects, but rarely asks what technology is' (Oliver, 2016: 35). In this study, AR- and AI-based educational technology and holography are theorised as tools. Tools can be categorised as external/physical tools (e.g., artefacts, instruments, etc.) and internal/psychological/symbolic tools (e.g., procedures, methods, concepts, etc.). In addition, external tools are designed to 'manipulate physical objects', and internal tools can be used for learners to 'influence people or themselves' (Verenikina, 2010: 19). In particular, Ausubel (2000) proposed that the 'advance organiser' is a kind of symbolic tool that can support learning. An advance organiser is 'a pedagogic device that helps implement these principles by bridging the gap between what the learner already knows and what he needs to know if he is to learn new material most actively and expeditiously' (Ausubel, 2000: 11). Therefore, the advance organiser is designed to support mental scaffolding so that learners can relate the new knowledge that they are learning to existing knowledge, thus support what Ausubel termed 'meaningful' learning.

Imagine as a hypothetical case, a young person who wished to learn about how traditional (clockwork) clocks work. We can imagine that, in principle, our learner could come to understand clock mechanisms by sufficient time spent deconstructing and reconstructing clocks—with a good deal of trying things out. That this empiricist approach is feasible is suggested given that people have managed to learn how to make clocks. Yet, of course, clockmaking was a skill developed over centuries, and through generations of clockmakers, who had access to their predecessors to teach them. Just being left to apply trial and error seems highly unlikely to be a successful strategy except perhaps for the very occasional savant. People become experts by learning from existing experts before engaging in their own research. (That does not imply an infinite regress: but rather that culture develops by incremental steps through building on the achievements of earlier generations.) Even our savant is not feasibly going to be able to learn about this focal topic simply through her own unsupported efforts. This is perhaps so obvious that it seems a banal point. Yet there is a strong tradition of autodidacts—people who are said to have learnt about some field—perhaps languages or advanced mathematics—without formal tutoring. This might seem to suggest that Vygotsky's model is not general: that although people can be inducted into aspects of the culture through the mediation of teachers or parents or more advanced peers—they can also sometimes manage without.

But these autodidacts do not learn mathematics (and certainly not foreign languages) unaided. For example, perhaps the savant had worked their way through Euclid's elements—in which case we might consider Euclid to be acting as the mediator of culture, even though he died many centuries ago. Perhaps the savant learned French by way of a French–English dictionary, a book of French grammar, and some novels with text in both languages. This would be a credit-worthy achievement, but it has been mediated by tools and indirectly by other humans who provided those tools. So, people do not only learn by engaging in shared activities with others, but also by reading books, listening to podcasts, watching videos, and so forth. Sometimes these tools have been designed with pedagogic intent: for example, an effective textbook will be designed with some of the features that a classroom teacher would adopt: initial simplification, focus on key ideas, logical structuring of topics, the reiteration of key points to consolidate learning, explicit cross-linking between concepts and topics—and so forth. So, mediation can be direct through engaging in shared activities, in the same place at the same time, or maybe indirect by providing tools using shared symbol systems. When this is done with pedagogic intent, the medium may be designed to scaffold development: but, as suggested above, this is challenging enough face-to-face, and without that interaction, there is no feedback from the learner, and no opportunity to modify the scaffolding process. A textbook is a fixed resource—and although it can be used in myriad ways (e.g., one does not have to start with Chapter 1 and read through each paragraph once in the order it is found in the text), it is for the user to know how to manage this process.

Since within this perspective human mind is considered to be constructed by cultural and social influences (Vygotsky, 1978), tools are culturally and socially constructed. Therefore, a child can use tools which are external or internal to his or her mind to mediate the relationships with the wider social context and the world. Through mediation, children can use tools, including, for example, AR apps, holography and AI-based tools (see Sect. 18.5), to learn new things and construct new understanding. Below, we develop this notion of tools mediating learning, in relation to new educational technologies. This brings us to our second consideration, which is the focus on this book being on learners up to 8 years of age. Here we consider the implications of Piaget's (1970, 1972) work in his programme of genetic epistemology. As is widely known, Piaget posited a series of four stages of cognitive development, the most advanced of which (formal operations) is largely unavailable before the stage of secondary education. The preceding stage, of concrete operations, tends to develop in the later years of primary education. So it is largely unavailable to many of the children considered in the present volume. According to the Piagetian model, younger children have not yet developed the structures that support the kinds of abstract thinking that is available to older children and adults. Now the details of Piaget's work have been much critiqued in a number of ways. At the 'top' end, it has been claimed that Piaget's stage of formal operations does not represent the endpoint of human intellectual development, and at the 'bottom' end, it has been argued that young children are capable of engaging with some quite abstract ideas when these are presented in appropriate ways. The details of these debates are beyond our present chapter, but despite these various criticisms, there is little doubt that the thinking of young children is qualitatively different from adults, and that human cognitive development involves a gradual acquisition of intellectual sophistication (Piaget, 1959, 2020). So, for example, it has been argued that when it comes to science education, a very different emphasis is needed in the early years:

> Although the deficit assumptions drawn from Piagetian perspective have rightly been challenged, to a large extent teaching the formal theories and models of science, and therefore teaching canonical meanings for the specialist terminology, is not viable for children at this age. What is possible, is offering rich experience of natural phenomena, based on substantial engagement in observing, thinking and talking about, and representing (in language, in diagrams, in models, in gestures, etc.) what has been observed. This type of activity acts as entry level participation in scientific inquiry by building important scientific habits – careful observation, describing, questioning, explaining, representing, etc., and moreover such experience supports rich conceptualisations, and so provides the resources for later when canonical ideas will be introduced. Engagement in scientific enquiry might be considered to be an extension of play – recruiting a mixture of wonder, puzzlement, trying things out – where possible in the natural environment. (Taber, 2019: 359)

One area where limited maturation limits the potential for young children to learn from learning resources is in the area of metacognition (Whitebread et al., 2007). Metacognition concerns thinking about thinking, and metacognitive development involves such matters as being aware of the limits of one's knowledge, being able to reflect on the coherence of one's thinking, evaluating whether teaching reinforces, extends or challenges what one already thinks, and so forth. Clearly, a high level of metacognitive sophistication supports effective study as it allows the learner to plan, monitor and adapt their learning activities (White & Mitchell, 1994). So, deciding to skip the rest of this section if it is all too familiar, re-reading a chapter that did not seem to make sense, judging that an especially unlikely sentence is probably just a typographical error and not something to be concerned about, recognising indicators of a website that might be trusted as authoritative, making judgements about when apparently definitive statements could represent out-of-date material or idiosyncratic authorial opinion. In other words, something like a textbook can often mediate effective learning despite the absence of direct interaction with the author, and the static and linear nature of the resource, if the learner has the study skills to use the resource flexibly and reflectively, and so, in effect, increases the tool's potential to offer scaffolding of the learning process. In the present chapter, however, our assumption will be that children of the age we are concerned with here generally lack the metacognitive sophistication to overcome the limitations of learning resources which do not have a degree of interactivity built into them. This is where new educational technologies have particular potential—at least to the extent that they can support learners engaging with them interactively, through affordances built into the mediating tool.

When working with AR apps, AI-based and holographic technologies, these tools take the role of the 'more capable peer'. Once the learner is capable of completing the task individually, his or her ZPD will be expanded for that particular task and 'what the learners cannot do now' for that particular task will be shifted as the learner's ZPD is itself modified. Through mediated engagement with activity, learners are able to complete more and more difficult tasks and grasp a more profound understanding of particular topics. This concept was initially formulated to challenge the psychometric-based assessment system, which only reflects students' current level (zone of actual development, ZAD) without investigating their potential for development. When learners work in the zone of distal development (ZDD, i.e., beyond their ZPD), they are not able to construct understanding based on current capabilities in their ZAD (see Fig. 18.1).

In formal classrooms, mediation in Vygotsky's model usually involves an adult of 'more capable peer' present to guide learners' learning. Teachers can use many technologies as tools, including interactive boards, tablets and laptops, to present teaching materials, organise scaffolding activities and help students construct new knowledge. Therefore, face-to-face interaction enables mediation to happen. However, learners often engage in self-regulated and self-directed learning in out-of-class contexts; learners set their learning goals, and actively engage in, control and monitor their learning behaviours, or adjust cognitions, to achieve the learning goals in self-regulated learning (Zimmerman, 1989, 2000). Therefore, learners have to build up new ideas and construct the outline for the new knowledge without teachers' support in out-of-class contexts; children often undertake self-directed study with or without parental guidance, and sometimes a 'more capable other' might not be physically present to mediate learning. Although mediation can take place vicariously through the use of external and internal tools, and the use of digital technology in out-of-class contexts allows the learner to work at his or her own resolution, it can be hard for children during their early childhood to be equipped with sophisticated metacognitive awareness (see above) to effectively manage his or her learning activities in out-of-class contexts, especially when parental guidance is not available. In this situation, if digital technology can be effectively used for children in early childhood to learn science in out-of-class contexts, the tools have to be equipped with scaffolding potential so that the learner can effectively work in his or her ZPD. Therefore, a number of AI-based tools have been invented with features of resources that can help young children with limited metacognitive awareness to identify their ZPD, and to provide them with individualised guidance and act as the 'more capable peer' (we further discuss the use of AI-based tools in Sects. 18.5.3 and 18.6.1 in this chapter).

## 18.5 Tools Available for Children in Early Childhood to Learn Science

In this section, we discuss the features of resources which can offer experiences to make otherwise abstract ideas seem more concrete and support young children's science learning as mediation tools. In particular, AR apps, holography and AI-based tools are focused, and we discuss to what extent these tools offer these features.

### *18.5.1 Augmented Reality Apps*

The augmented reality application (AR app) is one of the top categories in the App Store. Although AR has been widely used in the entertainment industry (e.g. 'Pokémon Go' and 'Harry Potter: Wizards Unite' which are provided by Niantic, Inc.), more genres of AR apps are being developed, and most of the apps available can be briefly categorised into five groups:

1. entertainment (e.g. games, virtual dolls, virtual pets);
2. art-related (e.g. creating, sketching, drawing);
3. room/space plan (e.g. architecture, landscape design, house floor plan, furnishing);
4. administrative tools (e.g. scanner, measurement);
5. science-related (e.g. creatures/plants recognition, anatomy, universe, solar system, stars and planets exploration, AR museums, human body/organs).

We carried out a systematic literature review on the Web of Science database; keywords including 'Augmented Reality'/'AR', 'Science Learning' and 'Early Years' were searched; 14 results were generated. All of these studies have been published since 2010, which shows that AR-based science learning in early years is still a developing field of research. Some of the research focused on the use of AR to promote preschool children's foreign language learning (e.g. Topsakal & Topsakal, 2019); one study focused on supporting early school age children's empathy behaviour with

AR storybook (Gil et al., 2014); some of the research studies argued that AR could be effectively used to promote STEM education; however, none of these research studies focused on early childhood science learning contexts. Therefore, we identified a literature gap that relatively little research had been carried out to study the use of AR-based apps in out-of-class science learning of early years learners, despite AR apps having been shown to have great potential for enhancing achievement and motivation in science learning. This was also the case among secondary school-age learners (Gnidovec et al., 2020; Kularbphettong et al., 2018; Lasica et al., 2019).

Simulation plays an important part in learning; and in more recent years, games that combine simulation aspects have been used by teachers and learners in formal and out-of-class contexts (Mitchell & Savill-Smith, 2004). For example, it could be argued that many curriculum supporting tools (e.g. PhET) have the element of gaming to motivate learners; and indeed, it has been suggested that there is no clear distinction between games and educational simulations (Podolefsky, 2012). In fact, these educational games with simulation aspects help reinforce formal and out-of-class learning and have great potential to improve learners' learning motivation and cognitive development (de Freitas & Levene, 2004; Jiwa & Lavelle, 2003; Squire, 2002; Woods, 2004). Since leisure-based games are not primarily designed for learning, there might be a lack of pedagogical design and learning theory which could affect learning outcomes (de Freitas & Oliver, 2006). However, many research studies focused on the use of leisure-based games in educational contexts (e.g. Prensky, 2001), and some research showed that non-educational games could effectively improve secondary school age learners' science learning engagement and motivation (Deslis et al., 2018). In particular, some of the 'entertainment-related AR apps' are closely linked with out-of-class science learning. For example, one of the most popular AR games, 'Pokémon Go', had illustrated its educational values in relation to science learning. Pokémon (The Pokémon Company) are fictional 'species' developed by Japanese scientist Satoshi Tajiri (Shelomi et al., 2012), inspired by his enjoyment of insect collecting while he was a child (Time, 1999). With the AR function, users can actually 'see' the Pokémon play around in their surroundings. While most of these 'species' do change their appearance, the original translation of Tajiri's work used 'evolution' to describe this metamorphosis process (Shelomi et al., 2012). When 'catching' a Pokémon with a Poké Ball in 'Pokémon Go', users can learn the type (fire, water, grass, etc.) and gender of a particular Pokémon, and 'watch' them 'evolve', etc. Since some of the features in 'Pokémon Go' are science-related, there are debates on whether Pokémon can be used in science education. Although there are arguments regarding its negative effects on science education since the word 'evolution' is misused in the context of Pokémon's narrative (Chamary, 2016), and it is argued that Pokémon species do not adhere to the biological species concept (Shelomi et al., 2012); the philosophy behind Pokémon universe represents the biological change to an extent, the idea of biological change, which can be useful especially in biology learning.

Debates were raised about the purposes and aims of science education in the twenty-first century; some researchers argued that we should shift from teaching science to children so that they can be better prepared to pursue further study, to paying more attention to the 'understanding and appreciation of science' which can then be adopted in daily life (Braund & Reiss, 2004: 2). In line with this position, Reiss, Millar and Osborne argued that the science curriculum 'should provide sufficient knowledge and understanding to enable students to read simple newspaper articles about science and follow TV programmes on new advances in science with interest' (1999). Unlike VR technology, in which learners cannot sense the real world around them, AR 'supplements reality, rather than completely replacing it' (Azuma, 1997: 356). Therefore, learners still have the opportunity to see the real world around them with the use of AR; and when playing AR-based games like 'Pokémon Go' in science learning, children can also start to learn to think critically and scientifically—what is 'evolution', what is the difference between an 'animal' and a 'plant', etc., which are all important skills not only in science learning but also in our daily life.

Since digital elements can be immersed into the existing reality, AR feature does not only offer experience to make otherwise abstract ideas seem more concrete but also changes the way that children interact with abstract and 2D scientific concepts as mediating tools, which can help children construct knowledge much easier with fewer demands on their existing cognitive skills. For example, a child is able to 'see' the solar system and 'twist' the planets in the bedroom (see Sect. 18.6.2) through the screen of a smartphone or a tablet; he or she is also able to 'create' a jumping dinosaur in a room with the use of AR apps. However, since children cannot view things without looking through the screen when using AR apps, holographic tools can complement AR because they can offer children in early childhood more direct visualisation for otherwise abstract notions. We then provide a very brief introduction of holography in early childhood science education in the following section.

### *18.5.2 Holography in Early Childhood Science Education*

Holography has been widely adopted in advertising, performing arts, tourism and the entertainment industry. Japanese holographic pop star Hatsune Miku had her first concert in 2010. A Chinese holographic singer, HeZ, became the first holographic singer who participated in a talent show in 2017. Nowadays, we can see holography in many galas and concerts; however, they have rarely been used in the field of education despite the great potential of the technology.

In recent years, holography has been gradually receiving attention in the field of education (e.g. Ghuloum, 2010; Park et al., 2020). For instance, several researchers have demonstrated that holographic based tools can present realistic images to learners (Kalansooriya et al., 2015) and provide opportunities for learners and teachers 'physically' present even if they are from different locations (Campbell & Santiago, 2016). In particular, holographic technology can be useful in science learning (Turk & Seckin-Kapucu, 2021; Walker, 2013); many research studies showed that it could improve science learning motivation (Orcos & Magrenan, 2018), help visualise abstract concepts (Roslan & Ahmad, 2017; Turk & Seckin-Kapucu, 2021), provide alternative learning opportunities and make the knowledge acquired more memorable.

We carried out a systematic review on the Web of Science database; we searched keywords including ‘Hologram’, ‘Science Learning’ and ‘Early Years’; only two results were generated. One of the studies found that moving visualisations (including hologram) are effective in facilitating learning for children up to ten years old (Kanellidou & Zacharia, 2019). We then tried to search using keywords, ‘Hologram’ and ‘Science Learning’, to see whether there would be more research studies in wider contexts, and 181 results were generated. It is not surprising to note that relatively more research studies focused on the technical development of holograms, including deep learning and machine learning (e.g. Eybposh et al., 2020; Horisaki et al., 2018). In terms of the research in the field of education, some of the studies found that holograms can enhance degree level learning of science-related subjects (Moro et al., 2020); some of the research studies focused on exploring the effectiveness of using holographic tools for primary school age learners (Orcos et al., 2017) and secondary school age learners (Jeon, 2000; Orcos et al., 2019). One of the research studies focused on the use of holographic technology in pre-school contexts, and discussed the effectiveness of adopting visualisation tools to enhance literacy in English language (Barkhaya et al., 2018).

Holographic technology can also provide a realistic learning environment (Kalansooriya et al., 2015). For example, if a child wants to learn more about the difference between the ‘Eighty-eight Butterfly’ and the ‘Morpho Menelaus’,but it might be hard for him or her to see these butterflies in real life, then with the help of holographic projection, the child would be able to ‘see’ them fly in his or her bedroom directly. It can be seen from the systematic literature review that holograms can present abstract knowledge in concrete ways, and they can motivate learning and improve teaching and learning efficiency. Therefore, holography can act as the mediating tools and support young children’s (science) learning. However, despite the great potential that holograms can contribute to science learning, how to use holographic tools in science education is a relatively under-researched field (Turk & Seckin-Kapucu, 2021).

There are some professional holographic tools (although not primarily designed for education) available on the market. HoloLens 2 debuted in 2019; it is a wireless headset projecting holographic pictures that allow users to see and interact with holograms and 3D images. Its price tag is 3500.00 US dollars at the time of writing, and although this seems relatively expensive compared with other popular educational technologies (e.g. iPad), many researchers are trying to develop affordable hologram-making tools and portable learning kits (e.g. Park et al., 2020). Prices can be expected to fall as the technology becomes more widespread: smartphones and personal computers were very expensive when they were first available on the market; however, many of them became accessible with reasonable prices because of the lower unit costs of mass production and manufacturing. We can foresee that holography will be made available to a wider community in the near future as the market matures, and this will open up more opportunities for supporting young children's science learning as mediating tools. Since it is recommended that holograms can be adopted to enhance the sense of reality in science education through the concretisation and visualisation of abstract concepts (Turk & Seckin-Kapucu, 2021), we provide practical suggestions and options to design a simplified version of hologram in Sect. 18.6.3.

### *18.5.3 Artificial Intelligence in Early Childhood Science Education*

AI can offer immersive interaction in early childhood science education, which can complement face-to-face education, online education and distance education. Unlike holography which has rarely been adopted in education, AI-based tools (including devices and mobile apps) have been increasingly used to assist teaching and learning; and there are some AI-based tools which have been used by children in homes (Eguchi, 2021). In addition, many AI approaches and systems have demonstrated their potential for supporting various forms of educational activities (Tuomi, 2018). We carried out a systematic literature review on the Web of Science database, searching for 'AI Tools' and 'Educational Research' as keywords; it is not surprising to note that 667 results were generated, including publications from 2010 to 2021, which indicates that this is a relatively well-established field of research comparing with the use of AR-based and holographic-based tools in education. We then refined the results by only including publications in Social Sciences Citation Index (SSCI); finally, 115 publications were reviewed; five publications focused on science (or STEM) learning with AI-based tools (Chin et al., 2010; Flogie & Aberšek, 2015; Koć-Januchta et al., 2020; McLaren et al., 2011; Nye et al., 2021); among these research studies, one research had been carried out in higher education context (Koć-Januchta et al., 2020), and the rest of them focused on primary or secondary school contexts.

Although many studies have focused on higher education contexts (e.g. Zawacki-Richter et al., 2019), there are increasing numbers of AI-based tools targeting children in early childhood due to the growth of market size. The popularity of smart mobile devices among children can be explained by their technological features, including screen size, weight, built-in affordance design, and so forth (Papadakis, 2016; Papadakis et al., 2016). However, many learners and teachers are still unclear about how to adopt AI to enhance teaching and learning experience. In the following subsections, we discuss the range of AI-based tools that children might access in early childhood science learning.

#### 18.5.3.1 Smart Lamp

The smart lamp is one of the most advanced AI-based educational technologies nowadays. In addition to the lighting and eye protection functions, a smart lamp is often equipped with two built-in cameras—one facing the child and another being installed at the top of the lamp overlooking the learning activities powered by AI. They also have functions such as learning guidance, learning activity management, speaking recognition, photo recognition and verbal communication. Furthermore, a smart device is being installed at the bottom of the lamp, making it easier for children to look at when they sit in front of the desk (see Fig. 18.2). Although it looks like a smartphone, the built-in operating system is dedicatedly designed for learning rather than general use; therefore, children are not able to download games or other social media from the AppStore, which can prevent children from indulging in games.

Based on AI and big data, the smart lamp 'learns' from a child's learning activity to identify his or her ZPD. For example, when the child reads a book, he or she just needs to point at any words, images or sentences that he or she does not understand, the AI camera which is placed at the top of the smart lamp will automatically scan it and then an explanation will be offered. The smart lamp will also 'remember' the inquiry; after obtaining enough data, it can develop a database of information about the child's current competence and responses to guidance (and so in effect

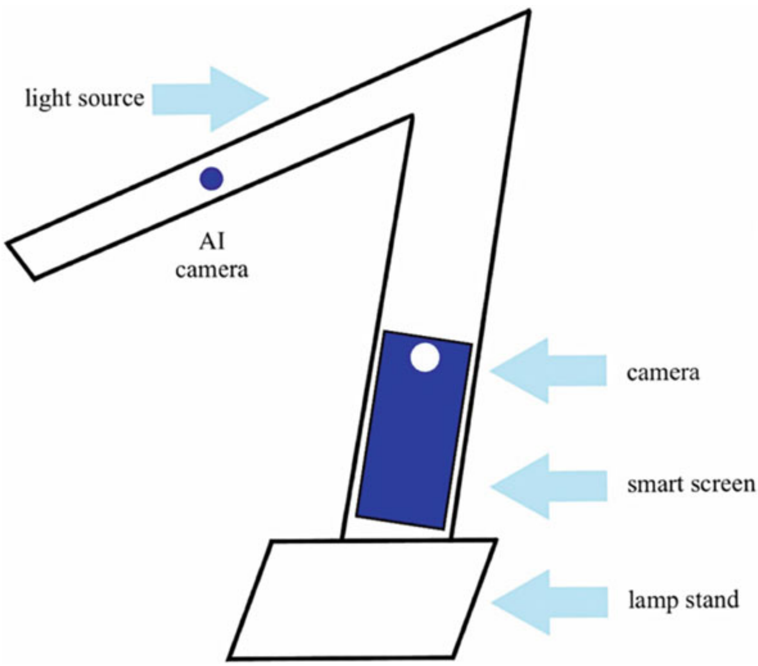


**Fig. 18.2** Model of the smart lamp

identifying the child's ZPD), and it will then be able to provide the young learner with personalised guidance, real-time voice reminders and learning materials. It is not only designed for science learning but can also be used to study other subjects at different levels from early childhood to secondary schools.

This is still a very new technology: most of the AI-based smart lamps have debuted since July 2020; the functions and characteristics of some of the more advanced products have only been announced since early 2021, but these products have not been made available to customers at the time of writing. Moreover, there are very few research studies focusing on the pedagogical and practical values of smart lamps at the time of writing—most of the published material regarding smart lamps is limited to press releases, news or media resources. This then is clearly a promising niche for research into the extent to which this tool can mediate learning in a child's ZPD.

#### 18.5.3.2 Smartphones

With the widespread ownership of mobile devices among school-aged learners (Bedesem & Arner, 2019), smartphones offered more opportunities, allowing learners to engage in various learning activities to learn science within and beyond the classroom (Nikolopoulou & Kousloglou, 2019). Some of the smartphones available are equipped with AI assistants, such as Amazon Alexa, Siri and Cortana, which can answer simple questions. Unlike the smart lamp discussed above, smartphones and these AI assistants are not dedicatedly designed for education. However, a child can still ask the AI assistant questions like 'what is a super moon', and the AI assistant may be able to provide simple explanations depending on different databases. Apart from this built-in feature, there are also many AI-based image recognition apps available in the App Store. For example, a child might come across a flower that he or she wants to learn more about; however, his or her parents may not be able to recognise the flower and explain further information to the child; the child just needs to take a photograph of the flower using the built-in camera of a smartphone, and use one of the apps which is dedicatedly designed for plant identification to recognise the photograph, and relevant information would be displayed on the screen. These AI-based apps constantly learn from human experts and specialists, the accuracy rate and database would be improved accordingly. Some of the apps can also 'read out' the information for younger children with limited literacy skills to understand the texts. These features can support young children's learning as mediating tools.

#### 18.5.3.3 Tablets

Tablets became commercially available in the market since 2002 (El-Gayar et al., 2011); Google launched its first commercial Android-based tablet in 2009, and the first generation of Apple iPad debuted in 2010 (Geyer & Felske, 2011). Nowadays, many technology companies, including Samsung, Microsoft and Lenovo had also produced tablets with different operating systems, which even increased the popularity and ownership of tablets; therefore, it is not surprising to note that many research studies had been carried out to investigate the impact that tablets have on education (e.g. Balanskat, 2013; Clarke et al., 2013; Schnackenberg, 2013). There are two types of tablets that are equipped with AR apps and AI apps or functions, namely the student tablet (e.g., Xiaoxin Pad designed by Lenovo) and general-purpose tablet (e.g., iPad designed by Apple, Galaxy Tab designed by Samsung).

The dedicated student tablets have similar appearances to the general-purpose tablets but usually come with lower prices; they have cameras, microphones, and some of the display screens are TÜV certified (using low blue light content to protect children's eyes). They are usually equipped with the AI learning assistant, helping children focus on learning but avoid spending too much screen time. The tablet can be set to block other irrelevant pop-ups while studying. The student tablets have built-in learning materials or courses, including science, language, mathematics and many other subjects. The tendency to spend much screen time on less educational activities can be thwarted by settings that can disable the ability to download or open non-vetted applications during 'study' time. The student tablets are designed to help children concentrate on learning rather than spending time on social media or playing games, being designed primarily for pre-school and school-age learners. The general-purpose tablets offer more AI-based apps in the AppStore compared with the designated student tablets. However, many of the AI-based apps currently available are designed for primary and secondary school students; there are not yet many science apps for pre-school age learners, either with AI or not. Therefore, this could be a market opportunity for apps developers.

#### 18.5.3.4 AI-Based Learning Robots—Individualised Learning Experience

The term 'educational robots' often refers to those robots which can help learners deepen their understanding of robotics and programming (e.g., LEGO Mindstorms; NAO). This builds on seminal work carried out in the 1960s and 1970s by Papert and his collaborators in their constructionist programme (Harel & Papert, 1991): the programming language 'LOGO' enabled children to programme a 'turtle' to move about in response to instructions. The turtle could be an icon on a computer screen but was initially a robotic device that physically moved around the classroom as programmed (Parmaxi & Zaphiris, 2014).

Many educational robots available now are not designed for early years learners since they require basic computational thinking, algorithmic understanding and mathematical and scientific knowledge to do the programming. However, some AI-based learning robots are being used by an increasing number of children. These AI-based learning robots are equipped with speech, text and image-recognition functions; they look like animated characters which children will readily engage with. These robots can read and explain scientific concepts in flashcards, textbooks and picture books; and children can learn science without parental guidance. In addition, some of the flashcards which are being sold together with the learning robots can display AR images once being scanned by children, which is a combination of AR and AI technology.

The AI-based learning robots can present scientific knowledge in an intuitive, concrete and vivid way through different teaching methods, including reading picture books, telling stories, playing games, displaying animations, playing music, and so forth; therefore, children can choose the most suitable learning materials according to their preferences and intelligences (Gardner, 1983), and learn through seeing, hearing and touching. Since many young children learn new things through touching, the touchscreen technology makes it easier for young children to explore and learn with mobile devices (Papadakis et al., 2017); the smart screens which are installed on these learning robots can be helpful for children in early childhood to learn many topics. These features of resources can support young children's learning as mediating tools.

One of the most advanced AI-based learning robots, with even more functions than those described above, currently costs a relatively modest approximately 100 GBP; therefore, it is highly possible that AI-based learning robots will increasingly become accessible to more children and support their science learning in the near future. We argue that these robots can be utilised in science learning for early years learners, and we further discuss the use of AI-based learning robots in Sect. 18.6.1.

#### 18.5.3.5 Scanning Pen

Picture books are popular learning resources for children (Horst & Houston-Price, 2016; Strouse et al., 2018). However, many picture books are published in English, making it hard for those whose mother tongue is not English to read. Moreover, because the translated versions are limited, some parents and children have to use dictionaries or digital translators to understand the contents. Compared with paper dictionaries that are difficult to carry and take longer to look up words, more parents and children choose to use mobile apps instead. However, it is hard for children in early childhood to use a smartphone to access those translation apps: they need a dedicated device which is specially designed for translation. With the development of AI technology, the scanning pen has been invented, which provides the opportunity for the sharing of educational resources in different languages worldwide.

The scanning pen looks like a normal pen but with a wider shape and a digital screen (see Fig. 18.3), a child can just hold it like holding a normal pen, press it lightly on the paper, and the recognition light of the pen would light up, which indicates


**Fig. 18.3** Representation of a scanning pen

that the AI camera is ready to work. Next, scan the word, sentence or paragraph that the child wants to translate at a constant speed like usual highlighting, and the translated text will be displayed on the smart screen of the scanning pen. Then, in less than 1 s after the end of the scanning, the original text and the translated text will be displayed on the screen, and the pen will 'read' out the text in the meantime. This can then be seen as a small step in transforming the static text into a more interactive system that can respond to a particular child's current state of learning. With the Optical Character Recognition (OCR), speech recognition, machine translation and other AI-based features being installed in the scanning pen, it provides children with a more efficient and lower-cost translation experience and supports young children's learning as a mediating tool; therefore, it also improves the learning efficiency.

## 18.6 Discussion

Technology supported learning is a topic attracting much attention in educational research, especially in areas such as mobile device assisted learning (e.g. Crompton & Burke, 2018; Foti & Mendez, 2014) and computer assisted learning (e.g., Beatty, 2013; Weinberger et al., 2005). However, early years science education remains an under-researched field (Taber, 2019). Furthermore, there is little research focusing on developing and adopting AR apps, holography and AI-based tools to support young children's science learning as mediating tools. Having offered a brief overview of the range of AR apps, holography and AI-based tools available to children in early childhood to learn science, we consider how might the technologies be developed to better act as tools to mediate learning in young children in the following subsections.

### *18.6.1 An Example of an AI-Based Tool Offering Scaffolding—Learning Robots*

As many AI-based tools are not generally designed by teachers or pedagogic experts with professional subject knowledge, some of those currently available offer little more than digitised versions of traditional textbooks, and the advanced AI features that can potentially mediate development have not been effectively used despite the immersive learning experiences they can offer. How to design AI-based tools to best offer learners productive learning experiences remains an under-researched field. Among AI-based tools, the learning robot is a particular focus in this chapter since they tend to be targeted at children in early childhood, which is a core concern of this book.

The Chinese educator Confucius put forward the pedagogical precept of 'teach students in accordance with their aptitude'; however, it is very hard for teachers to design teaching methods to cater for each child's needs. Gardner (1983) proposed the theory of multiple intelligences (MI), and he suggested that people have a profile of different kinds of intelligence. Gardner proposed that there are eight major types of intelligence, namely, visual-spatial, linguistic-verbal, interpersonal, intrapersonal, logical-mathematical, musical, bodily-kinaesthetic and naturalistic intelligence (Watson & Skinner, 2012). Therefore, he argued that 'We have this myth that the only way to learn something is to read it in a textbook or hear a lecture on it…Everything can be taught in more than one way. And anything that is understood can be shown in more than one way' (Edutopia, 2009: para. 9). Vygotsky would have agreed with this stance—part of his work concerned what is sometimes referred to today as 'accommodations'—finding alternative compensatory modes of learning to support those with various disabilities, such as the visually impaired. Children's intelligence profiles can be different, and a child might be particularly strong in one of the intelligences as proposed by Gardner. For example, suppose a child is strong in visual-spatial intelligence. In that case, it could be easier for him or her to learn through visualisation, and this child would be good at interpreting pictures. If a child is strong in linguistic-verbal intelligence, he or she might be good at reading, and he or she may learn better with written or verbal texts.

When designing an AI-based tool, an intelligent system could be set up to engage the learner through their particular strength(s) or could be set to preferentially engage (and so perhaps) develop weaker elements of the profile. As we discussed earlier, some AI-based learning robots can tell stories, display animations, play music, etc.; therefore, they could offer personalised learning materials based on training with extensive data. Once the robot has collected some data regarding a child's learning habits, the robot will be able to personalise its interaction with the child. For example, a robot could notice that the child reacts to images faster than to text, and the robot might mark this as the feedback; subsequently, the robot might preferentially present information as images when these are available from the accessible database. Thus, the tool is 'intelligent' as the more data the robot has collected and marked, the better matching of learning materials and teaching methods to the particular child.

Some AI-based learning robots can read and explain scientific concepts from flashcards, textbooks and picture books; these are essential features of resources that can offer experiences to demonstrate abstract scientific knowledge in more concrete ways. In addition, AI-based learning robots can provide children with opportunities to choose where to study, when to study, whom to learn with and what to learn. The AI-based functions could improve children's science learning motivation and help children better construct scientific conceptions without parental guidance. For example, a child may ask 'why are the leaves green', the robot will answer the question 'verbally'; some more advanced robots will also display pictures of examples or play animations on the built-in screen, and they may also tell relevant stories. With different forms of information, the AI-based learning robots go beyond simply offering sources of information; children can learn through listening, seeing and touching, and the learning robots offer young children immersive and interactive experiences to better support their science learning as mediating tools.

According to Taber (2002: 74), there are certain criteria for scaffolds:

1. They must ask the learner to undertake an activity/task which is beyond their present ability if unsupported;
2. They must provide a framework of support within which the learner can be successful by relying on the structured support;
3. They must provide reduced support as the learner becomes familiar with the area, and is able to cope with increased demands; and
4. They must result in the learner being able to undertake (unsupported) the activity/task which was previously beyond them.

In order to scaffold children's learning, teachers are looking to get students working in their ZPD by setting up learning activities beyond their ZAD and offering them suitable support in classroom contexts. Yet this is a challenging task for the educational professional, and for pre-school age learners who spend more time learning in out-of-class play contexts, it is not reasonable to expect parents or learners themselves to (even implicitly) effectively identify the ZPD by themselves. Therefore, a user's ZPD identification should be one of the foci when developing AI-based learning robots which can better act as tools to mediate learning in young children.

AI-based learning robots are potentially able to identify children's ZPD for them, and by responding to the specific learner, they can help each child bridge from his or her ZAD to new knowledge. The more data in relation to a child's ZAD and learning habits that the learning robots can collect, the more precisely they can work in a child's ZPD and the more finely tuned support they can offer. Therefore, the learning robots do not only teach the child but in a sense will also learn and 'grow' with the child. The robots complement and supplement the teacher or parent by acting as an auxiliary 'more capable peer' offering individualised learning experiences and helping a young child with limited metacognitive awareness by scaffolding science learning.

There are some research studies that focus on learning with tablets and smartphones; however, there is currently very limited evidence reporting the advantages and disadvantages of using AI-based tools in early childhood science education; more research studies need to be carried out as there are more and more AI-based tools being released for learners in early childhood on the market.

### *18.6.2 An Example of an AR App Offering Scaffolding—Night Sky*

One of the differences between virtual reality (VR) and AR is the role that real life environment plays. VR simulates reality; it provides immersing experiences and shuts out the real world around the users. With the help of VR devices (e.g. Samsung Gear VR, Sony PlayStation VR), users can be located in places far from the users or even in imagined environments. For example, VR could offer learners the simulated experience of exploring the moon's surface, of surveying the biodiversity of a coral reef, and so forth. However, AR blends digital elements or enhancements into users' existing reality; these add-on elements can be separated from reality easily if needed. Therefore, it is argued that AR-based tools can effectively promote learning (Antoun et al., 2018; Mayilayan, 2019; Thornton et al., 2012); in particular, AR-based educational game plays an essential part in enhancing learning experiences (Ierache et al., 2018) and improving science learning motivation (Bressler & Bodzin, 2013; Laine et al., 2016). However, little research had been carried out in the context of early childhood science education, which is a literature gap that requires more research evidence. There are increasing numbers of AR apps targeting science education. We discuss Night Sky as an example. Night sky is a 'guide to the sky above', and it is an AR planetarium; it helps 'Quickly identify stars, planets, constellations and satellites above by simply holding your iPhone, iPad or Apple Watch to the Night Sky!' (AppStore, 2021). It has a straightforward design, and the built-in affordance makes it easy to use even for young children. Night Sky has an outstanding resolution ratio which creates an immersive learning experience. It also offers interactive functions; children can zoom in and twist to view stars, planets, telescopes, etc., from different angles. With the AR function, a child can project a space telescope onto his or her desk. These are essential features of resources that can offer experiences to make otherwise abstract knowledge seem more concrete and support young children's learning as mediating tools.

However, this app is not primarily designed for young children; therefore, it presents jargon which can be difficult for children to understand. In addition, some pages include a good deal of text which can be challenging for children to read. In order to better act as tools to mediate learning in young children, AR apps need to use accessible language which can be easily understood by most of the children in early childhood, and it would be better if there is a different balance between the use of images and text on each page.

### *18.6.3 An Example of the Simplified Holographic Tools for Visualisation*

As discussed above, there are relatively well-developed AI- and AR-based tools which are potentially beneficial to be adopted in early childhood science learning; however, there are relatively fewer holographic tools available for out-of-class science learning in early years. Therefore, we provide a practical-related guidance for designing the simplified holographic tools for visualisation in this section.

The innovative learning experience provided by holography focuses on the sense of presence and presentation. For example, holography could represent three-dimensional (3D) pictures of plants and animals in front of learners as if they were in the room. These factors are important in students' online learning (Kyei-Blankson et al., 2019; Swan, 2002); therefore, we argue that such an engaging way of learning can improve children's science learning motivation and improve their scientific understanding. Furthermore, because holography can provide young learners with a

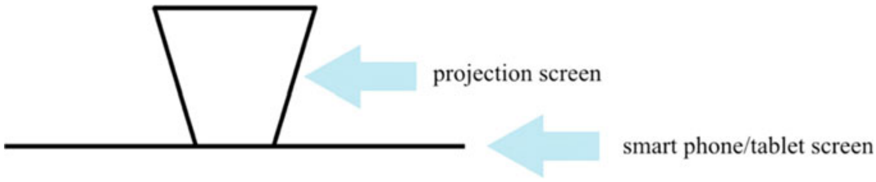


**Fig. 18.4** DIY 3D holography

much greater sense of presence comparing with 2D pictures and videos, the mixed reality learning approach promises a novel way of constructing an understanding of natural phenomena in real life. Although holographic sources, which are designed for early childhood science education, remain limited at the time of writing, parents can create simplified versions of 3D holography with transparent plastic and 2D videos, which can project many 2D creatures as 3D apparitions. This is quite a straightforward process with steps that can readily be followed:

Step 1: Cut the transparent plastic into four isosceles trapezoids;
Step 2: Combine them using sellotape and make a funnel-shaped tetrahedron (like a pyramid without a top);
Step 3: Search for 3D hologram videos on a smartphone or tablet, and place the tetrahedron in the centre of the video (see Fig. 18.4). Children can then be able to see the holographic projection on the screen, which is presented by the transparent plastic, when the video is played.

From the 'constructivist' perspective, ideas introduced by teachers in science teaching need to be constructed and developed from children's existing conceptions and experiences, and these ideas cannot be presented in a conceptual vacuum (Taber, 2009, 2019). With the simplified 3D holography mentioned above, we can help children learn a diverse range of scientific knowledge, including the shape of animals, the structure of organs, the structure of DNA, etc., in more concrete ways; therefore, holography has the potential to provide better visualisation and interaction, which can help support young children's learning as mediating tools.

## 18.7 Conclusion

The present chapter provides a new synthesis of ideas and explores potential benefits of the increasing use of AR apps, holography and AI-based tools in early years science education, from theoretical and practical perspectives. After systematically reviewing the existing literature, we identified a literature gap, which is the lack of exploration and discussion of the use of AI-, AR-, and holographic based tools in out-of-class early years science education, despite the positive influence that these tools can contribute to these specific learning contexts. In order to fill in this literature gap, we have discussed the features of resources that can offer experiences to make otherwise abstract ideas seem more concrete, the features of resources that can support mediation, and how might the technologies be developed to better act as tools to mediate learning in young children.

In previous research studies, there is a lack of theorising of the technological tools that we discussed here; therefore, we offered an alternative way to understand technology from pedagogical and psychological perspectives, which is one of the original contributions of the present chapter. Drawing on Vygotsky's notions of the zone of proximal development (ZPD), tools and mediation, and Piaget's ideas about children's development and their gradual acquisition of the cognitive structures needed to make sense of formal science concepts, the emphasis of the present chapter is on employing AR apps, holography and AI-based tools as progressive ways of mediation to enhance children's learning in science education. Although the development of these advanced technologies cannot be fully foreseen today, we believe that they can change the landscape of early childhood science learning by providing immersive and interactive experiences, and supporting children's conceptual thinking and scaffolding. In responding to our research questions, providing more intuitive ways of interaction and visualisation are the most important features of resource that can offer experiences to make otherwise abstract ideas seem more concrete; tools with these technical features as well as the consideration of ZPD can support young children's learning as mediating tools. Many AR- and holographic based tools offer features of intuitive interaction and visualisation. Features of identifying users' ZPD and presenting learning materials accordingly can be found in many AI-based tools. Technologies need to be developed from both interactive (e.g. including 'fun' elements; enabling various ways of interactions between learners and the tools) and pedagogical perspectives (e.g. drawing on learners' ZPD to enhance the effectiveness of the tools in educational contexts) to better act as tools to mediate science learning in young children. In addition, more research studies and tools are needed; given how difficult to optimise working in the ZPD, it is not enough to design tools with these affordances. There is also a need for a programme of research exploring how well these tools do engage learners in their ZPD, and so informing further tool development.

This exploration leads us to argue that AR apps, holography and AI-based tools offer innovative modes of interaction between young children and learning materials; therefore, these technologies can enhance the mediation of children's learning and improve early years science learning experiences. By discussing technology assisted science education from a new perspective, the present chapter can fill in a gap in the existing literature; and it can inform parents, teachers, researchers and developers (hardware and software) in the field of educational technology and early childhood science education. This chapter sets out some of the hard core commitments into developing AR apps, holography and AI-based tools to support effective early years science pedagogy; since some of the tools which are discussed in this chapter can be used for broader contexts and not limited to science learning, this chapter can serve as the basis for future research in early childhood education.

## References

Antoun, S., Auda, J., & Schneegass, S. (2018). SlidAR: Towards using AR in education. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia* (pp. 491–498).

Ausubel, D. P. (2000). *The Acquisition and retention of knowledge: A cognitive view*. Kluwer Academic Publishers.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments, 6*, 355–385.

Balanskat, A. (2013). *Introducing tablets in schools: The Acer-European Schoolnet tablet pilot*. European Schoolnet.

Barkhaya, N. M. M., Abd Halim, N. D., & Yahaya, N. (2018). Development of 3DPH: HoloRead for preschool children's learning. In *2018 IEEE 10th International Conference on Engineering Education (ICEED)* (pp. 246–250). IEEE.

Beatty, K. (2013). *Teaching & researching: Computer-assisted language learning*. Routledge.

Bedesem, P. L., & Arner, T. (2019). Mobile learning in and out of the K-12 classroom. In *Advanced methodologies and technologies in modern education delivery* (pp. 839–849). IGI Global.

Braund, M., & Reiss, M. (2004). *Learning science outside the classroom*. RoutledgeFalmer.

Bressler, D. M., & Bodzin, A. M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted Learning, 29*(6), 505–517.

Campbell, A. G., & Santiago, K. (2016). Future mixed reality educational spaces. In *Proceedings of the 2016 Future Technologies Conference (FTC)* (pp. 1088–1093).

Chamary, J. V. (2016). 'Pokémon Go' is bad if you don't understand evolution. *Forbes Magazine*, 29th July, 2016.

Chin, D. B., Dohmen, I. M., Cheng, B. H., Oppezzo, M. A., Chase, C. C., & Schwartz, D. L. (2010). Preparing students for future learning with teachable agents. *Educational Technology Research and Development, 58*(6), 649–669.

Clark, K., Logan, R., Luckin, A. M., & Oliver, M. (2009). Beyond Web 2.0: Mapping the technology landscapes of young learners. *Journal of Computer Assisted Learning, 25*, 56–69.

Clarke, B., Svanaes, S., & Zimmermann, S. (2013). One-to-one tablets in secondary schools: An evaluation study. *Tablets for schools*.

Crompton, H., & Burke, D. (2018). The use of mobile learning in higher education: A systematic review. *Computers & Education, 123*, 53–64.

de Freitas, S., & Levene, M. (2004). An investigation of the use of simulations and video gaming for supporting exploratory learning and developing higher-order cognitive skills. In *Proceedings of the IADIS Cognition and Exploratory Learning in the Digital Age Conference* (pp. 35–42).

de Freitas, S., & Oliver, M. (2006). How can exploratory learning with games and simulations within the curriculum be most effectively evaluated? *Computers & Education, 46*, 249–264.

Deslis, D., Kosmidis, C. V., & Tenta, E. (2018). Using a non-educational mobile game for learning in biology, geography and mathematics: Pokémon go as a case study. In *International Conference on Technology and Innovation in Learning, Teaching and Education* (pp. 388–396). Springer.

Edutopia. (2009). *Big thinkers: Howard Gardner on multiple intelligences*.

Eguchi, A. (2021). AI-powered educational robotics as a learning tool to promote artificial intelligence and computer science education. In *International Conference on Robotics in Education (RiE)* (pp. 279–287). Springer.

El-Gayar, O. F., Moran, M., & Hawkes, M. (2011). Students' acceptance of tablet PCs and implications for educational institutions. *Educational Technology & Society, 14*(2), 58–70.

Eybposh, M. H., Caira, N. W., Atisa, M., Chakravarthula, P., & Pégard, N. C. (2020). DeepCGH: 3D computer-generated holography using deep learning. *Optics Express, 28*(18), 26636–26650.

Flogie, A., & Aberšek, B. (2015). Transdisciplinary approach of science, technology, engineering and mathematics education. *Journal of Baltic Science Education, 14*(6), 779–790.

Foti, M. K., & Mendez, J. (2014). Mobile learning: How students use mobile devices to support learning. *Journal of Literacy and Technology, 15*(3), 58–78.
Gardner, H. (1983). *Frames of mind. The theory of multiple intelligences.* BasicBooks.
Geyer, M., & Felske, F. (2011). Consumer toy or corporate tool: The iPad enters the workplace. *Interactions, 18*(4), 45–49.
Ghuloum, H. (2010). 3D hologram technology in learning environment. In *Informing Science & IT Education Conference* (pp. 693–704).
Gil, K., Rhim, J., Ha, T., Doh, Y. Y., & Woo, W. (2014). AR petite theater: Augmented reality storybook for supporting children's empathy behaviour. In *2014 IEEE International Symposium on Mixed and Augmented Reality-Media, Art, Social Science, Humanities and Design (ISMAR-MASH'D)* (pp. 13–20). IEEE.
Gnidovec, T., Žemlja, M., Dolenec, A., & Torkar, G. (2020). Using augmented reality and the structure–behaviour–function model to teach lower secondary school students about the human circulatory system. *Journal of Science Education and Technology, 29*(6), 774–784.
Harel, I. E., & Papert, S. E. (1991). *Constructionism.* Ablex Publishing.
Harry Potter: Wizards unite. https://www.harrypotterwizardsunite.com
Horisaki, R., Takagi, R., & Tanida, J. (2018). Deep-learning-generated holography. *Applied Optics* (14), 3859–3863.
Horst, J. S., & Houston-Price, C. (Eds.). (2016). *An open book: What and how young children learn from picture and story books.* Frontiers Media SA.
Ierache, J., Mangiarua, N. A., Becerra, M. E., & Igarza, S. (2018). Framework for the development of augmented reality applications applied to education games. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics* (pp. 340–350). Springer.
Jeon, T. H. (2000). Making holograms in middle and Higgs schools. In *Proceedings of the Society of Photo-optical Instrumentation Engineers, 3831* (pp. 223–228).
Jiwa, S., & Lavelle, D. (2003). Evaluating the quality of learning through gaming and simuation. In *The international simulation and gaming yearbook* (pp. 233–235), vol. 11.
Kalansooriya, P., Marasinghe, A., & Bandara, K. M. D. N. (2015). Assessing the applicability of 3D holographic technology as an enhanced technology for distance learning. *Journal of Education, 1*(16), 43–57.
Kanellidou, M., & Zacharia, Z. (2019). Visualisations in primary education. Effects on the conceptual understanding of basic astronomy concepts for children up to ten years old. In *EDULEARN19 Proceedings of the 11th International Conference on Education and New Learning Technologies*, Palma, Spain, 1–3 July, 2019 (pp. 3080–3084). IATED Academy.
Koć-Januchta, M. M., Schönborn, K. J., Tibell, L. A., Chaudhri, V. K., & Heller, H. C. (2020). Engaging with biology by asking questions: Investigating students' interaction and learning with an artificial intelligence-enriched textbook. *Journal of Educational Computing Research, 58*(6), 1190–1224.
Kularbphettong, K., Roonrakwit, P., & Chutrtong, J. (2018). Effectiveness of enhancing classroom by using augmented reality technology. In *International Conference on Applied Human Factors and Ergonomics* (pp. 125–133). Springer.
Kyei-Blankson, L., Ntuli, E., & Donnelly, H. (2019). Establishing the importance of interaction and presence to student learning in online environments. *Journal of Interactive Learning Research, 30*(4), 539–560.
Laine, T. H., Nygren, E., Dirin, A., & Suk, H. J. (2016). Science spots AR: A platform for science learning games with augmented reality. *Educational Technology Research and Development, 64*(3), 507–531.
Lasica, I. E., Meletiou-Mavrotheris, M., Mavrotheris, E., Pitsikalis, S., Katzis, K., Dimopoulos, C., & Tiniakos, C. (2019). Enlivened laboratories within STEM education (EL-STEM): A case study of augmented reality in secondary education. In *Augmented reality in educational settings* (pp. 267–294). Brill Sense.
LEGO. MINDSTORMS. Retrieved from: https://www.lego.com/en-gb/themes/mindstorms

Mason, L., & Boscolo, P. (2000). Writing and conceptual change. What change? *Instructional Science, 28*, 199–226.

Mayilyan, H. (2019). Augmented reality in education, AR globe project assessment in actual teaching-learning environment. *International Journal of Learning, Teaching and Educational Research, 18*(3), 1–14.

McLaren, B. M., DeLeeuw, K. E., & Mayer, R. E. (2011). Polite web-based intelligent tutors: Can they improve learning in classrooms? *Computers & Education, 56*(3), 574–584.

Microsoft. HoloLens 2. Retrieved from: https://www.microsoft.com/en-us/hololens

Mitchell, A., & Savill-Smith, C. (2004). *The use of computer and video games for learning: A review of the literature.* Learning and Skills Development Agency, London.

Moro, C., Phelps, C., Jones, D., & Stromberga, Z. (2020). Using holograms to enhance learning in health sciences and medicine. *Medical Science Educator, 30*(4), 1351–1352.

Nikolopoulou, K., & Kousloglou, M. (2019). Mobile learning in science: A study in secondary education in Greece. *Creative Education, 10*(06), 1271.

Nye, B. D., Davis, D. M., Rizvi, S. Z., Carr, K., Swartout, W., Thacker, R., & Shaw, K. (2021). Feasibility and usability of MentorPal, a framework for rapid development of virtual mentors. *Journal of Research on Technology in Education, 53*(1), 21–43.

Oliver, M. (2013). Learning technology: Theorising the tools we study. *British Journal of Educational Technology, 44*(1), 31–43.

Oliver, M. (2016). What is technology. In N. Rushby & D. W. Surry (Eds.), *The Wiley handbook of learning technology*. Wiley.

Orcos, L., Arís, N., Fernández, C. E., & Magreñán, Á. A. (2017). Holographic tools for science learning. In *International Workshop on Learning Technology for Education in Cloud* (pp. 36–45). Springer.

Orcos, L., Jordán, C., & Magreñán, A. (2019). 3D visualisation through the hologram for the learning of area and volume concepts. *Mathematics, 7*(3), 247.

Orcos, L., & Magrenan, A. A. (2018). The hologram as a teaching medium for the acquisition of STEM contents. *International Journal of Learning Technology, 13*(2), 163–177.

Papadakis, S. (2016). Creativity and innovation in European education: 10 years eTwinning. Past, present and the future. *International Journal of Technology Enhanced Learning, 8*(3/4), 279–296.

Papadakis, S., Kalogiannakis, M., Orfanakis, V., & Zaranis, N. (2016). Using scratch and app inventor for teaching introductory programming in secondary education. A case study. *International Journal of Technology Enhanced Learning, 8*(3/4), 217–233.

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2017). Designing and creating an educational app rubric for preschool teachers. *Education and Information Technologies, 22*(6), 3147–3165.

Park, M. S., Choi, Y. H., Ha, S. J., Gentet, P., Lee, J. H., Hwang, L. H., et al. (2020). A feasibility study on the lifelong education program of holography using simple hologram making tools. *International Journal of Internet, Broadcasting and Communication, 12*(4), 128–136.

Parmaxi, A., & Zaphiris, P. (2014). The evolvement of constructionism: An overview of the literature. In *International Conference on Learning and Collaboration Technologies* (pp. 452–461). Springer.

Piaget, J. (1932/1977). *The moral judgement of the child*. Penguin Books.

Piaget, J. (1959/2002). *The language and thought of the child* (3rd ed.). Routledge.

Piaget, J. (1970/1972). *The principles of genetic epistemology* (W. Mays, Trans.). Routledge & Kegan Paul.

Podolefsky, N. (2012). Learning science through computer games and simulations.

Pokémon Go. https://www.pokemongo.com/en-gb/

Prensky, M. (2001). *Digital games-based learning*. McGraw Hill.

Reiss, M. J., Millar, R., & Osborne, J. (1999). Beyond 2000: Science/biology education for the future. *Journal of Biological Education, 33*(2), 68–70.

Roslan, R. K., & Ahmad, A. (2017). 3D spatial visualisation skills training application for school students using hologram pyramid. *International Journal on Informatics Visualisation, 1*(4), 170–174.

Schnackenberg, H. (2013). Tablet technologies and education. *International Journal of Education and Practice, 1*(4), 44–50.

Shelomi, M., Richards, A., Li, I., & Okido, Y. (2012). A phylogeny and evolutionary history of the Pokémon. *Annals of Improbable Research, 18*(4), 15.

Squire, K. (2002). Cultural framing of computer/video games. *Game Studies, 2*(1).

Strouse, G. A, Nyhout, A., & Ganea, P. A. (2018). The role of book features in young children's transfer of information from picture books to real-world contexts. *Frontiers in Psychology, 9*, 50.

Swan, K. (2002). Building learning communities in online courses: The importance of interaction. *Education, Communication & Information, 2*(1), 23–49.

Taber, K. S. (2002). *Chemical misconceptions—Prevention, diagnosis and cure, Volume 1: Theoretical background*. Royal Society of Chemistry.

Taber, K. S. (2009). *Progressing science education: Constructing the scientific research programme into the contingent nature of learning science*. Springer.

Taber, K. S. (2018). Scaffolding learning: Principles for effective teaching and the design of classroom resources. In M. Abend (Ed.), *Effective teaching and learning: Perspectives, strategies and implementation* (pp. 1–43). Nova Science Publishers.

Taber, K. S. (2019). Exploring, imagining, sharing: Early development and education in science. In D. Whitebread, V. Grau, K. Kumpulainen, M. M. McClelland, N. E. Perry, & D. Pino-Pasternak (Eds.), *The SAGE handbook of developmental psychology and early childhood education* (pp. 348–364). Sage.

Taber, K. S. (2020). Mediated learning leading development—The social development theory of Lev Vygotsky. In B. Akpan & T. Kennedy (Eds.), *Science education in theory and practice: An introductory guide to learning theory* (pp. 277–291). Springer.

Taber, K. S., & Brock, R. (2018). A study to explore the potential of designing teaching activities to scaffold learning: Understanding circular motion. In M. Abend (Ed.), *Effective teaching and learning: Perspectives, strategies and implementation* (pp. 45–85). Nova Science Publishers.

Taber, K. S., & Li, X. (2021). The vicarious and the virtual: A Vygotskian perspective on digital learning resources as tools for scaffolding conceptual development. In A. M. Columbus (Ed.), *Advances in psychology research* (Vol. 143, pp. 1–72). Nova.

Thornton, T., Ernst, J. V., & Clark, A. C. (2012). Augmented reality as a visual and spatial learning tool in technology education. *Technology and Engineering Teacher, 71*(8), 18–21.

Time. (1999). The ultimate game freak.

Topsakal, E., & Topsakal, O. (2019). Augmented reality to encourage preschool children in foreign language learning. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics* (pp. 286–294). Springer.

Tuomi, I. (2018). *The impact of artificial intelligence on learning, teaching, and education.* Publications Office of the European Union.

Turk, H., & Seckin-Kapucu, M. (2021). Innovative technology applications in science educations: Digital holography. *Journal of Education in Science, Environment and Health (JESEH), 7*(2), 156–170.

Verenikina, I. (2010). Vygotsky in twenty-first-century research. In *EdMedia+ innovate learning* (pp. 16–25). Association for the Advancement of Computing in Education (AACE).

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Walker, R. A. (2013). Holograms as teaching agents. In *Journal of Physics: Conference Series, 415*(1). IOP Publishing.

Watson, T. S., & Skinner, C. H. (2012). *Encyclopedia of school psychology.* Springer Science & Business Media.

Weinberger, A., Ertl, B., Fischer, F., & Mandl, H. (2005). Epistemic and social scripts in computer-supported collaborative learning. *Instructional Science, 33*(1), 1–30.

White, R. T., & Mitchell, I. J. (1994). Metacognition and the quality of learning. *Studies in Science Education, 23*, 21–37.

Whitebread, D., Bingham, S., Grau, V., Pino Pasternak, D., & Sangster, C. (2007). Development of metacognition and self-regulated learning in young children: role of collaborative and peer-assisted learning. *Journal of Cognitive Education and Psychology, 6*(3), 433–455.
Winter, J., Winterbottom, M., & Wilson, E. (2010). Developing a user guide to integrating new technologies in science teaching and learning: Teachers' and pupils' perceptions of their affordances. *Technology, Pedagogy and Education, 19*(2), 261–267.
Woods, S. (2004). Loading the dice: The challenge of serious video games. *Game Studies, 4*(1), 207.
Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education—Where are the educators? *International Journal of Educational Technology in Higher Education, 16*(1), 1–27.
Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology, 81*, 329–339.
Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation: Theory, research, and applications* (pp. 13–39). Academic Press.

# Chapter 19
# Let's Get Cellphilming! Expanding the Use of Participatory Visual Methods with Young Children

**Joshua Schwab Cartas, Prudence Caldairou-Bessette, and Claudia Mitchell**

**Abstract** Cellphilming (cellphone + video) is an increasingly popular participatory visual method, especially in the time of social distancing. Unlike other methods such as Photovoice, Cellphilming has rarely been used with young children (under 8, preschoolers). In this chapter, we provide theoretical and practical firsthand accounts on the use of the Cellphilm method with young children. Two examples of working with 3- and 4-year-olds in an at home setting during COVID-19 are described to illustrate and reflect on the method. The chapter can support researchers, teachers and other tutoring adults to use Cellphilming to allow young children to express themselves on matters that concern them. We also propose Cellphilming as an opportunity for ethical education about the use of mobile devices and the Internet.

**Keywords** Cellphilm · Participatory visual methodology · Young children · Mobile device · New technologies · Digital citizenship

## 19.1 Introduction

The use of various participatory visual methods to foster the engagement and empowerment of participants in research and practice continues to expand (Gubrium et al., 2019; MacEntee et al., 2021; Mitchell & Sommer, 2016; Mitchell et al., 2017;

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Teachman & Gibson, 2018). One of these methods is known as Cellphilming. It is a form of participatory video using cellphones, or other mobile devices, which is becoming more and more popular, especially in the context of Covid-19 and social distancing (MacEntee et al., 2021). Although Cellphilming has been used with many different groups of adults, elders, youth and children (mostly over 8), it has rarely been used with young children, while other participatory visual methods such as Photovoice have been (Blaisdell et al., 2019; Pascal & Bertram, 2009). In this chapter, we present and describe the use of a Cellphilm method with children as young as 3 years old, offering two reflexive accounts of what we term ‘a pilot experience’ at the McGill Cellphilm Festival. To frame these reflexive accounts, we start with a consideration of the broad area of participatory visual methodologies with young children. We then go on to consider the two examples. Drawing on these two accounts, we provide guidelines, lessons learned and recommendations for researchers, teachers or parents wanting to use this method. We conclude by offering a critical reflection on the idea of Cellphilming as a promising participatory visual method for young children supported by adults to express themselves. Ultimately, we see this as an expansion of mobile technology use in the digital age.

## 19.2 Participatory Visual Methodologies (PVM) and Young Children

Almost two decades ago, Ewald and Lightfoot (2002) published their book on photography with young children, *I Wanna Take Me a Picture*. The book was an important one in its recognition of the power of technology in allowing children as young as four or five to curate their world. Since that time there have been of course many advances in technology, but also great strides in both participatory work and the idea of “decolonizing” childhood, something highlighted in Mitchell and Reid-Walsh’s (2002) book *Researching Children’s Popular Culture*. The approach of Participatory Visual Methodologies (PVM) that developed more formally in this line is now well known. Gubrium and Harper (2013) define participatory digital and visual methodologies as “rich multimodal and narrative data guided by participant interests and priorities, putting the methods literally in the hands of the participants themselves and allowing for greater access to social research knowledge beyond the academy” (p. 13). Moreover, Switzer (2018) notes “projects working with PVM vary significantly in scope and breath, they often reflexively combine the visual as a mode of inquiry, representation and engagement” (p. 191). Common PVM approaches include Photovoice (Wang & Burris, 1997), Drawing and Mapping (Theron et al., 2011), Participatory Video (Milne et al., 2012; White, 2003) and more recently Cellphilming (MacEntee et al., 2016; Mitchell et al., 2016). To date, there has been a paucity of work on Cellphilming with young children (between the ages of 3 and 8). Building on two examples, we will share the various steps involved in creating a No Editing Required (NER) Cellphilm (Mitchell & Sommer, 2016), as well as how to introduce young participants to the important issue of visual ethics. We also recommend best practices when it comes to supporting and facilitating the various steps, such as storyboarding, filming and screening/self-reflexivity. In particular, we explore how this participatory visual methodology not only familiarizes children to making their own digital media, but interestingly it allows them to engage with a wide range of literacies or meaning making processes. Tan (2019) reminds researchers that children speak in a variety of modes, which means that listening to young children "is a process that is not limited to the spoken word" (p. 68). It can also include "pre-verbal children, [which] require a process which is open to many creative ways young children use to express their views and experiences" (p. 68).

## 19.3 Children and Mobile Devices

Over two decades ago Prensky (2001) introduced the idea of children and young people as digital natives. Later, Twenge and Park (2017) referred to children as being part of the *iGen*, a generation shaped by the smartphone and the rise of social media. Indeed, most children in the global North grow up in digital homes (Chaudron, 2015) immersed by a rich array of digital media and tools.

This digital technology and new media has engendered what Jenkins (2006) refers to as a participatory culture, where everyday citizens participate in this participatory ecology, not as passive consumers, but rather as prosumers or active participants creating and distributing their own DIY (Do-It-Yourself) content on diverse social issues, such as gender, race, or the environment. Mitchell (2017) notes that DIY videos made by youth, tend to address and or vocalize important social concerns of their generation, such as climate justice (for example Indigenous water activist Autumn Peltier or Greta Thunberg), gender representation, identity, language, or cultural revitalization (Schwab-Cartas, 2018). This DIY media creation is no longer created or directed towards adolescents or young adults. A quick browse of YouTube will reveal thousands of child media creators, such as nine-year-old Ryan Kaji, from Ryan's World[1] who reviews toys online for other children. Children from a very young age grow up not only watching YouTube or TikTok videos for entertainment, but just as importantly use these, user-created videos, as an informal DIY means of learning a myriad of subjects and/or topics, from learning how to make bread, learning an Indigenous language to simply finding how to complete a video game. Of course, with the introduction of any new technology, Wartella and Jennings (2000) cogently point out that throughout the twentieth and twenty first century, there has always been a "great promise for social and educational benefits, [as well] as great concern for children's exposure to inappropriate and harmful content" (p. 31). This debate has included cellphones or mobile devices, such as tablets, as well. In fact, the proliferation and ubiquity of these mobile devices has given rise to a host of fears, related to the known possible impacts of screen time on different aspects of young

[1] https://ryans.world/.

children's lives (Guernsey, 2007). These impacts range from obesity (LeBlanc et al., 2017) and sleep (Tan & Fraser, 2021) to psychological well-being (Przybylski & Weinstein, 2019). In extreme cases some researchers, such as Michael Chen at the Children's hospital in Eastern Ontario, have compared children's propensity towards mobile devices and screen time to a cocaine addiction. However, for Przybylski and Weinstein (2019) "findings suggest that there is little or no support for the theory that digital screen use, on its own, is bad for young children's psychological well-being" (p. 6). Mobile devices like other technologies are always going to be a cause of concern no matter what era or what devices. As Stald (2008) has pointed out:

> to the users, the shell, the device itself, holds no or little affective value; it may be exchanged for a newer model. It is primarily the content and the representations it contains which establish the meaning of the mobile. Even if the mobile phone is regarded as a *personal* device, it is simply a *device*. The devices in themselves do not appear to be substitutes so much as conduits for affective and social bonds between people. (p. 158)

Nevertheless, these fears whether warranted or not, are common on the minds of parents, educators, researchers and facilitators. As we argue the Cellphilm method can assuage some of those concerns because it can function as an effective educational bridge that can help assist parents, educators and researchers on how to teach youth about responsible cellphone usage and digital safety. During Cellphilm sessions, which are structured, creative and provide a safe way of using mobile devices, tutoring adults can introduce potential dangers, such as cyberbullying, trolls, appropriate and inappropriate content to be shared and/or uploaded, as well as issues of privacy.

## 19.4 Cellphilm as a PVM

"The term *Cellphilm* was coined by Dockney and Tomaselli (2009), who combined two words—cellphone and film—to mark the convergence of multiple communication technologies in one device" (MacEntee et al., 2019, p. 421). Cellphilming as a participatory visual method both builds on participatory visual research, specifically participatory video, but also responds and directly engages with the participatory, peer-to-peer media culture engendered by the rapid development of digital technology and media of our age. Furthermore, as a method, Cellphilming also builds upon the everyday citizens, whether they are adults or children's, media making skills and their adept knowledge and ease with digital media/technology. As a methodology, Cellphilming is also keenly attuned to the fact that digital technologies, as Jewitt (2009) has noted, the communication landscape has been altered in significant ways due in large part to these mobile technologies, which now enable a mode of communication and literacies that are multimodal in nature, including image, sound, writing, movement and nonverbal gestures; all of which Jewitt states have a significant impact on the way we communicate. We mention this as a means to foreground that the Cellphilm approach adapted for children underscores the multimodal mode of communication that is part of their everyday experience as digital natives.

There are various levels of technical sophistication that could be used creating a Cellphilm. These could range from more traditional approaches to participatory video which requires storyboarding, script writing, editing, insertion of music and or sound, to filming approaches (i.e. *cinéma vérité*, interview, observational). However, Claudia Mitchell and Monica Mak, in a course at McGill University called "Visual Methodologies for Social Change" developed a filming method known as No-Editing-Required (NER) approach based on a pause-shoot-pause-shoot style "which speeds up video production considerably and allows for the creation of multiple scenes without the use of complicated editing software" (Treffry-Goatley et al., 2017, p. 50). Mitchell et al. (2016) would later develop another expeditious Cellphilming adaptation known as the One-Shot-Shoot (OSS) approach, which is a Cellphilm made in one continuous shot with no pauses and no editing. However, like the pause-shoot-pause approach to NER, it does require very careful storyboarding and planning. The OSS and NER share the same principles, which Mitchell et al. (2016) describe as key steps: (1) having lead-in time to contextualize the work; (2) a brainstorming session allowing participants in small groups to voice their ideas on the topic; (3) individual voting for the most important idea; (4) creating a storyboard around the chosen topic (including attending to such conventions as title and credits); (5) learning how to work with the camera; (6) shooting the video; (7) screening the video; and (8) immediate reflection on the first viewing (what works; what would you do differently?) (p. 437).

## 19.5 A Mosaic Approach to Working with Children

The *Mosaic approach* put forward by Allison Clark and colleagues (Clark, 2001; Clark & Moss, 2011) represents some of the most critical work that has been done in the last 25 years to include very young children in participatory research. As Tan (2019) writes, the Mosaic Approach is a "participatory learning in action way of listening, which acknowledges children and adults as co-constructors of meaning. It is an integrated approach which combines the visual with the verbal" (pp. 68–69). It could also include participatory analysis so that the child participant is involved in meaning-making. For this reason, it is key that our work on including children in Cellphilming integrates this approach. As noted above, there are a number of steps in the process of Cellphilming and part of our job as adults is to be able to listen, interpret, but also assist a young child in all the different steps to be able to produce a Cellphilm that expresses the child's message in an ethical and collaborative manner. In this way, the Cellphilm method is compatible with a Mosaic Approach, which combines "tiles" of multimodal perspectives to involve young children, and even very young ones (under 2), in research (Clark, 2005, 2010). These "tiles" can include observations, child conferencing (formal and informal conversations), interviews with people in the environment (siblings, parents and others), as well as photographs, structured activities, tours or mapping, to better comprehend the child's perspective on a particular subject or concern, for example, their nursery. Each of the many steps in Cellphilming (e.g. storyboarding, filming, screening), we propose could be seen as a "tile", and each could be seen as providing an interpretive and expressive opportunity within a mosaic approach. Each step evokes a particular set of ideas and thoughts in the child, so when a step is looked at both individually and collectively, coupled with children's own interpretation of their Cellphilm it can create a richer and perhaps more accurate perspective that the young participant was trying to put forth. It results in a "multimodal ensemble" (Jewitt, 2017) that can better represent the voice of children, something Lane et al. (2019) point out as a challenge.

## 19.6 Reflexive Accounts of Working with Young Children to Create Cellphilms: A Pilot Experience

Our methodology for the study builds on the idea of researcher's reflexivity, drawing on the work of other parents-as-researchers working with young children. Galman (2018) in her ethnographic fieldwork with 3 transgender and gender non-conforming young children refers to Delamont's (2016) idea of "a tough-minded version of self-consciousness", noting "that the researcher is constantly reminded that she is her own best data-collection instrument but only if she is continuously self-conscious about her role(s) and actions" (In Galman, 2018, p. 165). Two of the co-authors of this chapter, Joshua Schwab-Cartas and Prudence Caldairou-Bessette, both participatory researchers and parents of young children took up the challenge presented by the McGill International Cellphilm Festival (COVID-19 edition, 2020) to involve children of any age, and embarked upon producing reflexive accounts based on their experiences of, in a sense, facilitating a home-based workshop. The production of these accounts aligns well with the growing attention to reflexivity and critical inquiry as a feature of facilitation in participatory research (See Burkholder et al., forthcoming; Garcia et al., in press). The tools and methods for creating these accounts included fieldnotes in documenting the experiences, re-viewing the Cellphilms with the children, in the case of Josh, documenting the process visually, and the discussions of the 3 co-authors over email, the phone and Zoom calls about reflections, observations and reflexive writing of the examples.

## 19.7 Cellphilm Story 1: Jeli and Joshua's Experience with Cellphilming

### *19.7.1 Joshua's Reflections*

*"I want to try too, dad!!!" is a phrase I hear quite often from my 4-year-old daughter, Jeli, every time she sees me pick up my mobile device (iPod touch) and begin shooting a short video or what she has come to know as a Cellphilm. As a researcher who has*

*developed and used Cellphilming in my own work* (Schwab-Cartas, 2016, 2018), *I often thought of introducing her to the participatory visual method, as a way to bond and co-create content, but I asked myself, is she too young? Will she understand the process and steps required to make her own Cellphilm? I also worried about potential effects of mobile devices on young children particularly in relation to her development or possible exposure to harmful content. However, a situation in 2020 came up that I saw as a great opportunity. Like most of the world at the time, Covid 19 had severely affected Montreal, which prompted scholars, such as my former supervisor and mentor Claudia Mitchell, to find ways to address the devastating effects this pandemic has had on people's lives and mental well-being. Mitchell, alongside several researchers from various institutions and grad students from the Participatory Cultures Lab at McGill, organized a special edition of McGill's International Cellphilm Festival, entitled "Well-being in the Time of Social Distancing" [1]. The festival was meant to be a virtual forum for students, parents, children, teachers, researchers and anyone who has been affected by the pandemic to share their experiences, frustrations, coping strategies and even provide viewers and participants with a bit of respite from the wearisome effects of the everyday during Covid 19. The organizers did not want to exclude anyone from the festival, so it was open to all filmmakers, including children of any age. This was something new for the festival and so the organizers included online tools and suggestions for parents. This festival provided a stage to find ways to adapt and make Cellphilming accessible for the first time to young children and as a result, several questions arose* (Schwab-Cartas, 2020b). *For example, how do we teach children about visual ethics in a way that is comprehensible? Can we collaboratively not only create Cellphilms, but analyze them as well? How will the child's perspective, voice and vision be understood?*

"Is my daughter too young to Cellphilm?" is the immediate question that came to mind when I told Jeli that we were going to create a Cellphilm for the 2020 McGill International Cellphilm Festival. This was followed by a host of other questions; such as is she too young to be engaging with mobile or digital devices? What are the risks of introducing your child to mobile devices? How can I teach my child how to use digital technology responsibly and safely?

I began the Cellphilm exercise with my four-year-old daughter, by first asking her if she wanted to create a Cellphilm for a festival, which required me to explain to her that her work would be viewed by many people, some whom would be friends and family, while others would be strangers. She at first seemed a bit apprehensive, so I showed her some examples, including some of my Cellphilms and then gave her a couple days to think about it. I should note she was always excited about creating her own Cellphilm, but the idea of having other people view it seemed a bit strange or as she put it "weird" and perhaps even intimidating. This, I felt, became a perfect opportunity, not only to talk to her about the festival, prizes and goals, but more importantly introduce the topics of digital safety and responsible digital citizenship.

I asked Jeli if she knew what a Cellphilm was, and it was no surprise she knew it was a video, something to watch for entertainment like her Elmo videos. I told her that Cellphilms can in part be a form of entertainment, but they also are meant to tell a story or a message about a specific topic, so I explained that they can be a way to share your opinion on something that is important to you. For example, I asked her as part of a prompt, what was important to her or something that mattered to her. She was curious about why the city takes down her swings in the wintertime. I said: "perfect! You can make a video showing how you play with the swings and how you get sad when they are taken down in the late fall and you can show it to someone in the city", I said, "perhaps the city councillor of our borough". Relating Cellphilming to a lived experience helped her grasp the abstract concept of making Cellphilms and sharing it with others as a means to express her views and/or concerns. During this discussion I was also able to broach the subject of the mobile device itself, presenting it to her, not as a mere form of entertainment, which she was used to, but to explain to her that it was a powerful device with many uses. I explained and underscored the point that it *always* required parental or adult supervision, explaining to her that this is not a toy, that in fact, it can be used also for bad things, such as cyberbullying, online strangers, so we need to be careful about what we share online (introduction to visual ethics) or that too much screen time (which she has experienced a few times) could also have a negative effect like making you grouchy, tired and even sad or angry. However, I tempered these concerns by saying that there are many good things that you can use your device for, such as making Cellphilms, talking to friends and family, knowing the weather, listening to music, taking pictures, watching videos, and learning languages through her apps.

Cellphilming, as I would come to learn, allowed me to address these concerns not only for myself, but for and with my daughter. I came to see Cellphilm as a great bridging device to help children use technology in a responsible and safe way, because adult facilitators (researchers, parents, teachers, etc.) can introduce them to potential harms, but also teach them about the upside and positive aspects of digital media/devices- responsible digital citizenship. This, in fact, represents a "practice of defining the norms of appropriate, responsible behaviour with regards to technology use" (Dotterer et al., 2016, p. 59). In this context of bonding while creating a Cellphilm, facilitators can reinforce the idea of what appropriate cellphone usage looks like, by setting out clearly defined boundaries for cellphone use, as well again as introducing children to big topics, such as potential harms of using cellphones and social media, cyberbullying or visual ethics (what is okay and not okay to share online and why).

In addition to introducing young children to potential harms and benefits of digital media, it is important, as I quickly learned from working and collaborating with my daughter, that young children are experts when it comes to digital media and technology, so it is important to find ways to not infantilize them despite their young age. Young children are meaning makers who can and do comment on their world and surroundings through a variety of mediums, such as song, drawing and crafts, and perhaps using a Cellphilm method or other visual methods can allow them to express it in a way that is more understandable to parents or older people. I mention this because part of using a participatory visual method is not only to use an exciting or more stimulating approach to data creation but also "helping the abstract become more concrete" (Scherer, 2016, p. 2). Using visual methods, like Cellphilming, as Mannay (2010) notes, is about "minimis[ing] the power relationship between adult researcher and child" (In Scherer, 2016, p. 2). It can be about finding meaningful ways to collaborate with children, not just as children, but as co-researchers, meaning-makers, in all aspects of the Cellphilm process, including the analysis and interpretation of visual data. As Lomax (2012) asserts in regards to children interpreting visual data, "it offers a more nuanced and rigorous approach to understanding image based data" (p. 227).

To Lomax's point, I would quickly learn that on many occasions, trying to read or interpret my daughter's Cellphilms, there would be gaps or simply misinterpretations, which my daughter would correct me on. Moreover, my daughter was very happy to share *her* thoughts, ideas and what her Cellphilms meant to *her*, but it helped me understand the nuances and complexity of ideas that this little four-year-old was trying to express through visual means. It also seemed that it helped her better express complex ideas, such as being an active citizen in her community. For example, she wanted to address what she felt to be a pressing matter in everyday life, which is littering, especially when she saw it at park she played with, making the point that glass bottles for instance are dangerous to kids like her and her peers. The point here is that the inclusion of little children moves away from that hierarchical power relation, which has tended to make children invisible, and towards more collaborative and horizontal connections, where both researcher and child participant can and do learn from one another. As many parents or adults working with little children will tell you, if you really make an effort to listen to them, you will learn a lot from them. I know my daughter continuously not only teaches me about life, but even about new ways to engage with technology. Cellphilms therefore are an accessible way to share information and data results across ages and speaker abilities. This can contribute to the reflection about what has been an issue of contention for years: how do we share results with our participants in participatory research?

## 19.8 Cellphilm Story 2: Marie and Prudence—From Home to the International Cellphilm Festival

### *19.8.1 Prudence's Reflections*

*I first learned about Cellphilms in a workshop given by Joshua Schwab Cartas in 2019 at McGill University's faculty of Education when I was just starting my postdoctoral fellowship in the Participatory Culture's Lab. I then had the opportunity to participate in making a group Cellphilm with students in one of Claudia Mitchell's class. This practice of using videos was all very new to me. Then the pandemic struck and I was home with my family (my partner, my 5 years old son and my 3 years old daughter) 24 h a day for 3 months. After viewing a video on the Cellphilm festival website, made* *by Schwab Cartas*[2] (2020a)*, indicating some ideas about how to create Cellphilms with children, I decided to participate in the 2020's festival and worked to engage my family. Marie, 3 years old, was the most interested in making a film with the cellphone. However, it was a challenge to be able to complete a Cellphilm with her and we only did it for the 2021's festival. Some of the questions that arose through this experience include the following: how to accompany young children in respect for their will and voice at the same time as adapting to the requirements of adult-led contexts (here the festival)? How to adapt participant-led method to the reality of very young children? How can we ethically understand and support young children in the making of a Cellphilm? Where does our own voice stand in that process and how should we position ourselves as adults helping them?*

*2020.* The theme of the 2020 Cellphilm festival was "Well-being in the time of distancing". I showed Marie how to make a Cellphilm using the app pausevideo.me, which allows an iPhone user to pause and resume filming (a function that is on all android phones), following the NER recommendations. I introduced Marie to the topic and asked her to film what she felt to be important things for her in the house, since we were at home all the time due to the pandemic. She made a video where she filmed: the computer, the water tap, the toilet, the bath, a bathing suit, the board games and the kids table in the living room, naming things as she filmed them, with her really small and happy voice, sounding like she was having a lot of fun (what we could call *the special permission effect* of getting to use a cellphone). The video was too long for the festival's contest. To respect the NER approach, it would have been necessary to do it again, but after doing it once she lost interest (or did not understand why she should do it again; she did it already!), so we did not move forward. However, we did end up submitting a family Cellphilm about baking bread, which was, as many families, our favourite experience at home during the pandemic. I have to admit this was easier than continuing to pursue a Cellphilm project with Marie. Indeed, working with small children can be very challenging, which is one of the main reasons for the underrepresentation of children in research (Glass, 2006) and in other areas of participation in the social space.

Marie's production that year did not become a Cellphilm, but in introducing things to her the way I did, I realized I was very much influenced by the Mosaic approach, which inspired my previous work with children under 5 (Caldairou-Bessette et al., 2018). The central idea of this approach is to listen to young children through diverse activities, including tours of a space that children live in; in our case, it was our house. The different activities bring all kinds of data together (verbal, nonverbal, image-based). Being a child psychologist, I am used to being attentive to details, body language, drawing and play to listen and try to understand small children. This understanding work is a hermeneutical work, where we try to bring pieces together into forming a meaningful whole, something like puzzling the tiles until what first appeared chaotic starts to make sense, in an effort get the message (Gadamer, 1996; Schwandt, 2014).

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[2] https://www.youtube.com/watch?v=CZFSCsIDL4c&t=675s&ab_channel=InternationalCellphilmFestival.

When I watched Marie's video again, I realized that it was much more telling than I initially understood. While filming the computer was not surprising because so much revolved around the computers during the pandemic, Marie herself also had a whole new experience of it. From talking to family, to special moments where she was allowed to watch online live storytelling with puppets every day at 11 am (I would then put my computer on her little kids table), this pandemic time at home transformed her relationship to computers. Then, her video seems to focus a lot on water (tap, toilet, bath, bathing suit) and this is interesting especially when looking at the Cellphilm that she made the next year.

*2021.* In 2021, Marie was now 4-year-old and her participation in Cellphilming for the festival happened in a very spontaneous way. After the 2020 Covid-19 lockdown, she had been back to kindergarten since the fall and it was now spring, but she was home again for 2 weeks due to a case of Covid-19 in her class. She was playing in the garden barefoot in the grass and she started to talk out loud about the importance of nature and water. I then told her about the 2021 Cellphilm festival, which the theme that year was on transformations after the Covid-19 situation that we were experiencing. She remembered the Cellphilm we did for the festival the year before. I told her that this year she could, if she liked, address a message to adults by video and that it could be seen by many adults. She was very excited about doing that and we started to talk about the things she wanted to say. She mentioned the importance of the planet for humans to live, the importance of trees and flowers, that they need water, that water is very important (including to put out fires) and she was adamant that we should not waste water because the planet needs it and will be "furious" ("furieuse"). She also said that we should not throw garbage around, and we should not watch too much TV because we can have headaches.

From there we began filming, whereupon we developed a series of signs that I would make to prompt her to start talking and when she had to say a last sentence. We did about 10 'takes' and I should note that she was very patient during all the takes, which showed how she wanted to do it, and she now understood why we should do it many times. When I saw that she was becoming annoyed, we stopped and took a break to look at the videos. I tried to discuss with her what her favourite video was, but she was not very receptive, so I did not keep on insisting. Looking later at the material on my computer, I realized that none of the shots were complete and all had important moments where a message was said more convincingly, and also that most of the videos were too long for the festival's requirements. Moreover, in the best one, we accidently saw her underwear. This was an occasion to discuss public images and intimacy with her. I finally decided to edit a video with the best parts. I tried to engage Marie in the editing process but she was not very interested, in part because it meant looking over and over again at videos she had already seen. I then took on the lead and finalized the Cellphilm not long before the deadline, unfortunately without discussing the title with Marie since she was not home when I needed to submit it. I finally wrote a title in very adult-like words that I thought represented her Cellphilm: "Necessary Post Pandemic Transformations According to Marie". I also put some sentences in English in the Cellphilm to represent the main points she wanted to say and make it somehow accessible to English speakers (Marie speaks French). Marie was very proud of her Cellphilm and we watched it together on a big screen with our family and her grandparents. This was an occasion for her grandfather to hear Marie say her important environmental message that we should not cut trees, while he did cut one for renovations in his yard. Marie also watched the virtual International Cellphilm Festival with me and while she was very disappointed not to have won, she was clearly engaged.

I think this experience can make us reflect on the role of the adults in children's participation, and the diversity and change in this role according to children's age. Indeed, children can use the help and support of adults to better understand their feelings and put their ideas into words or images, but they also depend on adults to mediate their voice to the world of adults, or to navigate the technologies and requirements of different forms of communications. So, our role as fostering children's participation is not only to listen, but also to transmit children's views, to represent them. In research, this can be understood as an ethical responsibility, as we have written elsewhere (Caldairou-Bessette et al., 2020). Ethically, we should be aware not to put forward our adult-centered understanding, but our understanding of children's views after listening carefully to them. In the representation of the perspectives of children, we are authors, but we are second authors. Our understanding is an interpretation, but should be an ethical one, where children come first, and we advocate for their voices and perspectives (McPherson & Thorne, 2000). The engagement and responsibility of the adult should be greater as the children are younger and more effort should be made to hear younger children, as they have the right to have their perspectives represented like all children (Palaiologou, 2014).

In editing Marie's video, I wanted to amplify her voice to be heard by adults, which was what she also wanted. My endeavour was not perfect, but I tried to honour her vision and my implicit engagement that her Cellphilm would be presented at the McGill International Cellphilm Festival. This experience has taught me different things, but most importantly about time management, agency and interpretation. I think that had I done the storyboard step it would have helped us better express the message in diverse and more fun ways, but also make the shots more effective, avoiding the experience of doing the same thing over and over again. I also feel like Marie's agency was influenced by my own knowledge and experience. Indeed, the more experience I got, the more I could accompany her, and the more experience she got, the more she could situate her voice in understanding the meaning of doing a Cellphilm. The more experience we gained, the more agency she could feel and mobilize (even if age also has a major influence of course).

As for interpretation, I think the action of giving a title to the Cellphilm is key and that it was very unfortunate that we skipped it. In writing this article, I went back to thinking about what Marie was communicating and how water seemed to have a special place when we put her two productions together. Wondering again about my understanding (am I hearing right?), I took the opportunity of asking Marie what she would have named her Cellphilm and her answer was: «The Water».[3] This shows

[3] I also asked her if it was ok for her that I write for other adults about our experience of Cellphilming together and she kindly agreed.

how the whole process of the Cellphilm, including the act of giving a title and the idea of an audience contributes, as noted earlier in this article, to the rigor and ethics of interpreting and understanding image-based data produced by children. It illustrates how listening is so important, but can always be continued, confirmed, or completed by another "tile", to use Clark's term, to help us picture things more clearly. In the days after, it became more and more clear to me how water was important to Marie, in all kinds of daily situations (for example she likes to bicycle especially when it is raining), but also allowed me to rediscover water in its symbolic dimension, as a source of life (Thompson, 2018), an incredibly pertinent theme during a deadly pandemic.

## 19.9 Learning as We Go Along

Seemingly what started as an innovative and socially distanced way to connect with others outside one's home, while also breaking up the monotony of being isolated from others as part of the Covid 19 pandemic, resulted in a promising approach for working with children by finding ways to adapt the PVM method of Cellphilming for very young participants. The collaboration between parent/researcher and child/participant being participatory in nature, extended well beyond simply, brainstorming and filming. In both of the accounts, the parent/researcher quickly learned that their young children almost organically became co-researchers by taking an active role in interpreting what would normally be construed as data. This is why participatory analysis (Nind, 2011) was used as yet another way of not only including the child participants into the data interpretation and meaning-making processes, but as a way to better *listen* and understand children's perspectives. The results of this short-term encounter or pilot experience yielded a series of soft data that can be used to further this approach for future research. For example, each step of the Cellphilm process yields visual, oral, and gestural data that when done in collaboration with the child participant creates a shared interpretive/listening opportunity for the adult to better understand the complexity of the child's message. Doing so, as Prudence notes in her story, helps us as adult collaborators to avoid the impulse to "correctly" or "better" interpret the data in a way that corresponds to an adult perspective/ideology. Instead, as we both learned from this encounter that children do have their individual perspective rooted in their own lived experiences regarding what they filmed. If only as adults, we are willing to listen and learn more subtle ways that children communicate. Cellphilming therefore becomes a medium with which children can make their message or perspective more comprehensible to adults like their parents, researchers, and/or educators, but it also illustrates collaboration with young children that goes beyond tokenism.

Some of the most pertinent work, we think, coming out of our pilot experiences of home-based facilitation is to offer some guidelines for others. While on the one hand we hope that these guidelines might assist parent, teachers, researchers, or any adults who would like to try Cellphilming with young children, we also offer them as ideas that could help to frame further study about what it means to do this kind of research with very young children.

## 19.10 Some Guidelines to Use Cellphilms with Young Children

**Share examples of Cellphilms**: Begin by showing your child/participant different examples of Cellphilms to familiarize them with different approaches and genres, such as PSA (public service announcements), stop motion, interview, talk show, or a show and tell. You can consult the McGill's International Cellphilm Festival website at: https://internationalCellphilmfestival.com/. On the homepage, if you scroll down, you will find an array of our past entries. Some fun and kid-friendly entries include 2019 *Be Kind to Bees* Produced by Vanessa Gold & Mitchell McLarnon, 2015 the Mountain by Patrick Richard, which is not to say that the others are not wonderful entries only that they deal with more involved themes or ideas.

**Offer participatory and fun prompts**: Prompts are tricky for anyone to develop, work with, and even comprehend at times, which is why they must be clear and easy to grasp. Of course, they can't be prescriptive and are specific from context to context depending on the issue or matter being addressed. When introducing a prompt to a young participant, mention that the prompt helps guide and shape what the video will be about, so it is important to have a fun discussion, keep it interactive and ask them questions surrounding the prompt to help them think about the prompt. Some examples can be: "A Day in the life of…", "The best part of my day…", "What I would like to tell adults is…".

**Adapt steps in making a Cellphilm to accommodate the child's attention span and interests**: A quick tip before you familiarize your child with a mobile device for this activity, it is important to keep your mobile device on airplane mode or offline to ensure that the young participant cannot go online unnecessarily or accidently.

<u>Step 1: Brainstorm</u>

When working with young children the brainstorming activity can be a bit abstract, but combining it with Step 2, storyboarding, can make it more tangible.

<u>Step 2: Storyboarding</u>

There are various ways of storyboarding. Josh found that every time he had done this activity/step with his daughter, she had insisted on colouring in her storyboard. This is a wonderful and important extra step in this process for several reasons. First by personalizing it through the act of colouring there is a greater sense of pride and ownership, especially if you helped draft up the storyboard itself, which is important to maintaining their level of excitement and interest in making their own Cellphilm. Secondly, colouring for many children is a fun and even relaxing experience, which can allow you to talk to them in a less forced or stringent context. Josh for example has observed that when he asked his daughter about ideas about her Cellphilm, she felt put on the spot and said she felt embarrassed, but when she was colouring she felt more at ease to speak about her ideas and feelings. Again, by them seeing images on the storyboard while they colour them, they begin to think about that scene in greater details and in a more concrete way what their Cellphilm is going to look like and thus evoking the adage of "seeing is believing". This process can be very generative of greater detail of each scene. It gets children to think visually, allowing them as they colour to recall greater detail of each scene they envision. It could be useful to write down their ideas on a separate sheet to help bring *their* vision to life.

Step 3: Filming

Before you film, ensure that you have enough free storage space and that your device is fully charged. Also instruct the child to hold their mobile device horizontally to make sure their video will be easy to view.

*Setting up visual cues with your child.* It is important to set up a nod or hand gesture system with your child to indicate when to start filming or if you are filming them when to start speaking so as to ensure you capture what they are saying. If not, you will constantly miss what they are saying and getting them to redo it too many times they will get fatigued.

*Rule of 3.* It may be tricky to ask a young child to redo a shot more than 3 times as it is a tiring process, something Prudence observed about her experiences with Marie. It is important for the parent, or facilitator to think out the shots and discuss with the child in greater detail to help them figure out their shot beforehand to ensure greater success. It is important to remind yourself it is about the child and as facilitators or parents we need to give up perfectionist tendencies of seeking the perfect shot or lighting etc. Too much time spent filming without breaks cannot only frustrate the child, but can result in the child not wanting to continue filming. Therefore, it is key to work in 15–20 min segments.

*NER filming—a caveat.* The NER (No Editing Required) approach does save time, but we suggest breaking up the time over several sessions, either with a pause in shots over a couple hours or at times an entire day. This gives the child time to unwind and also reflect on the process, but most importantly not to frustrate or deter the child from continuing the project. Also it can be okay to edit a child's Cellphilm and this can either be done with the child to help them express their vision or done without them as well. The important thing is to reflect on the ethics of it (what is most important for the child).

Step 4: Upload and Screening

This can be a great place to introduce the idea of who their audience is, their family and friends or someone beyond their immediate circle of people (who and why?). Here the parent or facilitator can decide whether this will be uploaded or not and if it is uploaded, parent/facilitator needs to keep in mind several factors, such as, who will be the audience, how will it be shared, what are potential risks, can it be taken down later. It may be on a big screen, but could also be the child's preference to watch the Cellphilm on the mobile device.

Step 5: Reflection and Future Action

We think that even very young children can offer very important reflections. The parent or facilitator needs to help in the process which can be done by coming up with a series of guiding questions that will help the child further contemplate the process, their Cellphilm and what they hope to achieve or future action. It is likely to be more effective in terms of the reflection process if the Cellphilm was watched several times and also spaced out between viewings. Here are some sample guiding questions:

- What did like about your Cellphilm? Why?
- Is there anything you would like to change?
- Who would you like to show your Cellphilm to? Why?

When working with younger children, another tip, coming from Holland's (2012) *War Child: Participatory Video with Children—Facilitators Manual,* suggests creating a chart with two columns, one with a smiley face and the other sad face as a means to help the child better express what they liked and did not like about their film. For example, ask the child how the sound was? What was their favourite scene? In this way even very young children can express a view, adding in their own voice to the reflexive process.

## 19.11 Conclusion

As a team, we have learned a great deal from this pilot experience. For Josh, the experience mirrors in some ways his doctoral and subsequent research where Cellphilming was used in research in the context of language revitalization and embodied learning (Schwab-Cartas, 2016, 2018). Indeed, Cellphilming can be deployed to create a multilayered experiential learning encounter. In the context of community, these encounters can invite youth to engage with ancestral practices, such as making tamales (Schwab-Cartas, 2012), while simultaneously learning language and documenting their Elders. The implication of this is that through this approach we can create a more inclusive approach to learning and adapting technology in the classroom to support different learning styles and abilities. For Prudence, the project aligned well with her interest in addressing ethical issues in her clinical and research work with children as well as to include children as participants in all contexts of life (Caldairou-Bessette et al., 2017).

In our two studies, cellphilming allowed the facilitator/researcher/parent to create encounters or situations where the mobile technology takes a secondary but perhaps incentivizing role for children, or what Prudence referred to as *special permission effect*, to get out of the habit of being on their device with no purpose. A Cellphilm approach is about using mobile technology (smartphone, tablet, digital camera) in a deliberate or purposeful manner that can complement an array of more mainstream education, such as science or math or history, within a school context. The child could create a Cellphilm about different bird species for example, or create a history report in the form of a Cellphilm which interviews parents or teachers to create a more polyvocal document.

Cellphilming is of course about using mobile technology, whether that is a cell phone or a tablet or even children's digital camera, such as Vtechboom, in a deliberate and purposeful manner to create a learning encounter. By deliberate we mean combining specific offline and online practices to create a *whole experience* that is embodied and takes as its central focus lived processes of creation. While technology is of course central to the process of Cellphilming, the role of technology is more of a conduit to motivate young children/youth to further learn about a particular subject. Therefore, these Cellphilm encounters not only reflect or embody everyday learning experiences, but can also assist young children through personal reflection to find ways to create greater balance in the role technology plays in their lives. It can help them develop ethical agency towards technology and beyond in different areas of learning and experience, so could be part of a broader approach to ethical education.

Finally, creating these reflexive accounts of our experiences of working/facilitating in a one-on-one context with our own children have helped us to better appreciate meaning-making through Cellphilming and also to help us envision what a pilot study with a larger group of young children might look like. In particular, we are interested in deepening an understanding of what is most valuable about Cellphilming to young children, in individual or group contexts. Added to this, we see Cellphilming as a fruitful area of study on digital safety. Taking our own precautions into account with our two different experiences, we recognize that many of the concerns that adults have about children's online safety, issues of privacy, cyber-bullying and so on can be addressed while having an engaging experience, making Cellphilming a mindful and intentional use of technology. These areas remain understudied within STEM, and yet they could so easily align with a parallel area of study in relation to amplifying children's voices. Let's get Cellphilming!

## References


Blaisdell, C., Arnott, L., Wall, K., & Robinson, C. (2019). Look who's talking: Using creative, playful arts-based methods in research with young children. *Journal of Early Childhood Research, 17*(1), 14–31. https://doi.org/10.1177/1476718X18808816

Burkholder, C., Aledebi, J., & Schwab-Cartas, J. (Eds.). (forthcoming). *Leading and listening to community: Facilitating qualitative, arts-based & visual research for social change.* Routledge.

Caldairou-Bessette, P., Nadeau, L., & Mitchell, C. (2020). Overcoming "You can ask my mom": Clinical arts-based perspectives to include children under 12 in mental health research. *International Journal of Qualitative Methods, 19*, 1–12. https://doi.org/10.1177/1609406920958959

Caldairou-Bessette, P., Nadeau, L., Vachon, M., & Rousseau, C. (2018, June 24–28). Creative methods to include children as participants in research: phenomenology and dialogue through play [Conference session]. In *The International Human Science Research Conference: Phenomenology and Dialogue: Exploring Questions of Language, Inclusivity and Accessibility*, Spartanburg, South Carolina, USA.

Caldairou-Bessette, P., Vachon, M., Bélanger-Dumontier, G., & Rousseau, C. (2017). La réflexivité nécessaire à l'éthique en recherche: L'expérience d'un projet qualitatif en santé mentale jeunesse auprès de réfugiés. *Recherches Qualitatives, 36*(2), 29–51. http://www.recherche-qualitative.qc.ca/documents/files/revue/edition_reguliere/numero36(2)/rq-36-2-caldairou-bessette-et-al.pdf

Chaudron, S. (2015). *Young children (0–8) and digital technology: A qualitative exploratory study across seven countries*. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC93239
Clark, A. (2001). How to listen to very young children: The mosaic approach. *Child Care in Practice, 7*(4), 333–341. https://doi.org/10.1080/13575270108415344
Clark, A. (2005). Listening to and involving young children: A review of research and practice. *Early Child Development and Care, 175*(6), 489–505. https://doi.org/10.1080/03004430500131288
Clark, A. (2010). Young children as protagonists and the role of participatory, visual methods in engaging multiple perspectives. *American Journal of Community Psychology, 46*(1–2), 115–123. https://doi.org/10.1007/s10464-010-9332-y
Clark, A., & Moss, P. (2011). *Listening to young children: The mosaic approach*. Jessica Kingsley Publishers.
Delamont, S. (2016). *Fieldwork in educational settings: Methods, pitfalls and perspectives*. Routledge.
Dockney, J., & Tomaselli, K. G. (2009). Fit for a small(er) screen: Films, mobile TV and the new individual television experience. *Journal of African Cinema, 1*, 126–132.
Dotterer, G., Hedges, A., & Parker, H. (2016). Fostering digital citizenship in the classroom. *Education Digest, 82*(3), 58.
Ewald, W., & Lightfoot, A. (2002). *I wanna take me a picture: Teaching photography and writing to children*. Beacon Press.
Gadamer, H.-G. (1996). *Vérité et méthode*. Éditions du Seuil.
Galman, S. (2018). The story of Peter-both-in-one: Using visual story-telling methods to understand resilience among transgender and gender non-conforming young children in rural New England. In A. Mandrona & C. Mitchell (Eds.), *Visual encounters in the study of rural childhoods* (pp. 161–175). Rutgers University Press.
Garcia, C. K., Mitchell, C., & Ezcurra, M. (in press). Not just any toolkit! What's facilitation got to do with it? In S. Shariff & C. Dietzel (Eds.), *IMPACTS: Reclaiming the role of universities to address sexual violence through multi-sector partnerships in law, arts and social media*. University of Toronto Press.
Glass, K. C. (2006). Taking a closer look at research with children (book review). *Ethics & Human Research, 28*(1), 18–19.
Gubrium, A., Fiddian-Green, A., Lowe, S., DiFulvio, G., & Peterson, J. (2019). Digital storytelling as critical narrative intervention with adolescent women of Puerto Rican descent. *Critical Public Health, 29*(3), 290–301. https://doi.org/10.1080/09581596.2018.1451622
Gubrium, A., & Harper, K. (2013). *Participatory visual and digital methods*. Routledge.
Guernsey, L. (2007*). Into the minds of babes: How screen time affects children from birth to age five*. Basic Books.
Jenkins, H. (2006). *Confronting the challenges of participatory culture: Media education for the 21st century*. John D. and Catherine T. MacArthur Foundation. https://www.macfound.org/media/article_pdfs/jenkins_white_paper.pdf
Jewitt, C. (2009). An introduction to multimodality. In C. Jewitt (Ed.), *The Routledge handbook of multimodal analysis* (pp. 14–27). Routledge.
Jewitt, C. (2017). *The Routledge handbook of multimodal analysis* (2nd ed.). Routledge, Taylor & Francis Group.
Lane, D., Blank, J., & Jones, P. (2019). Research with children: Context, power, and representation. *The Qualitative Report, 24*(4), 693–704. http://doi.org/10.46743/2160-3715/2019.3556
LeBlanc, A. G., Gunnell, K. E., Prince, S. A., Saunders, T. J., Barnes, J. D., & Chaput, J. P. (2017). The ubiquity of the screen: An overview of the risks and benefits of screen time in our modern world. *Translational Journal of the American College of Sports Medicine, 2*(17), 104–113.
Lomax, H. J. (2012). Shifting the focus: Children's image-making practices and their implications for analysis. *International Journal of Research & Method in Education, 35*(3), 227–234.
MacEntee, K., Burkholder, C., & Schwab-Cartas, J. (Eds). (2016). *What's a cellphilm?: Integrating mobile phone technology into participatory visual research and activism*. Springer.

MacEntee, K., Burkholder, C., & Schwab-Cartas, J. (2019). Cellphilms in public scholarship. In P. Leavy (Ed.), *The Oxford handbook of methods for public scholarship* (pp. 419–442). Oxford University Press. http://doi.org/10.1093/oxfordhb/9780190274481.013.13

MacEntee, K., Kendrick, C., & Flicker, S. (2021). Quilted cellphilm method: A participatory visual health research method for working with marginalised and stigmatised communities. *Global Public Health*. https://doi.org/10.1080/17441692.2021.1928262

Mannay, D. (2010). Making the familiar strange: Can visual research methods render the familiar setting more perceptible? *Qualitative Research, 10*(1), 91–111. https://doi.org/10.1177/1468794109348684

McPherson, G., & Thorne, S. (2000). Children's voices: Can we hear them? *Journal of Pediatric Nursing, 15*(1), 22–29. https://doi.org/10.1016/S0882-5963(00)80020-2

Milne, E.-J., Mitchell, C., & De Lange, N. (Eds.). (2012). *Handbook on participatory video.* AltaMira Press.

Mitchell, C., De Lange, N., & Moletsane, R. (2016). Me and my cellphone: Constructing change from the inside through cellphilms and participatory video in a rural community. *Area, 48*(5), 435–441. https://doi.org/10.1111/area.12142.doi:10.1111/area.12142

Mitchell, C., De Lange, N., & Moletsane, R. (2017). *Participatory visual methodologies: Social change, community and policy*. Sage.

Mitchell, C., & Reid-Walsh, J. (2002). *Researching children's popular culture: The cultural spaces of childhood*. Routledge.

Mitchell, C., & Sommer, M. (2016). Participatory visual methodologies in global public health. *Global Public Health, 11*(5–6), 521–527. https://doi.org/10.1080/17441692.2016.1170184

Nind, M. (2011). Participatory data analysis: A step too far? *Qualitative Research, 11*(4), 349–363. https://doi.org/10.1177/1468794111404310

Palaiologou, I. (2014). 'Do we hear what children want to say?' Ethical praxis when choosing research tools with children under five. *Early Child Development and Care, 184*(5), 689–705. https://doi.org/10.1080/03004430.2013.809341

Pascal, C., & Bertram, T. (2009). Listening to young citizens: The struggle to make real a participatory paradigm in research with young children. *European Early Childhood Education Research Journal, 17*(2), 249–262. https://doi.org/10.1080/13502930902951486

Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the Horizon, 9*(5), 1–6. https://doi.org/10.1108/10748120110424816

Przybylski, A. K., & Weinstein, N. (2019). Digital screen time limits and young children's psychological well-being: Evidence from a population-based study. *Child Development, 90*(1), e56–e65. https://doi.org/10.1111/cdev.13007

Scherer, L. (2016). Children's engagements with visual methods through qualitative research in the primary school as 'art that didn't work.' *Sociological Research Online, 21*(1), 1–16. https://doi.org/10.5153/sro.3805

Schwab-Cartas, J. (2012). Learning from communities: Personal reflections from inside. In E.-J. Milne, C. Mitchell, & N. De Lange (Eds.), *Handbook of participatory video* (pp. 383–396). AltaMira Press.

Schwab-Cartas, J. (2016). Living our language. In K. MacEntee, C. Burkholder, & J. Schwab-Cartas (Eds.), *What's a cellphilm? Integrating mobile technology into visual research and activism* (pp. 51–65). Sense. http://doi.org/10.1007/978-94-6300-573-9_4

Schwab-Cartas, J. (2018). Keeping up with the sun: Revitalizing Isthmus Zapotec and ancestral practices through cellphilms. *Canadian Modern Language Review, 74*(3), 363–387. https://doi.org/10.3138/cmlr.4056

Schwab-Cartas, J. (2020a). *2020 McGill International Cellphilm Workshop* [Video]. YouTube. https://www.youtube.com/watch?v=CZFSCsIDL4c&t=675s&ab_channel=InternationalCellphilmFestival

Schwab-Cartas, J. (2020b). *Let's get philming! A working guide to cellphilming with young participants.* McGill International Cellphilm Festival. Retrieved from https://internationalCellphilmfestival.com/2013/10/24/Cellphilm-tips/

Schwandt, T. A. (Ed.). (2014). *The SAGE dictionary of qualitative inquiry* (4th ed.). SAGE Publications.

Stald, G. (2008). Mobile identity: Youth, identity, and mobile communication media. In D. Buckingham (Ed.), *Youth, identity, and digital media* (pp. 143–164). MIT Press.

Switzer, S. (2018). What's in an image? Towards a critical and interdisciplinary reading of participatory visual methods. In M. Capous-Desyllas & K. Morgaine (Eds.), *Creating social change through creativity* (pp. 189–207). Palgrave Macmillan.

Tan, P. (2019). Listening to young children: A mosaic approach. *Simon Fraser University (SFU) Educational Review, 12*(2), 64–78. http://doi.org/10.21810/sfuer.v12i2.932

Tan, S.-C., & Fraser, J. (2021). Effects of screen time on sleep in children and adolescents: A systematic review. *BMJ Paediatrics Open, 9*(1), e023191. http://doi.org/10.1136/bmjopen-2018-023191

Teachman, G., & Gibson, B. E. (2018). Integrating visual methods with dialogical interviews in research with youth who use augmentative and alternative communication. *International Journal of Qualitative Methods, 17*(17), 1–12. https://doi.org/10.1177/1609406917750945

Theron, L., Mitchell, C., Smith, A., & Stuart, J. (Eds.). (2011). *Picturing research: Drawings as visual methodology*. Sense.

Thompson, J. A. (2018). *Women and water Wahala: Picturing gendered waterscapes in Southwest Cameroon* (Unpublished doctoral dissertation), McGill University. https://escholarship.mcgill.ca/concern/theses/h128nh190

Treffry-Goatley, A., Wiebesiek, L., De Lange, N., & Moletsane, R. (2017). Technologies of nonviolence: Ethical participatory visual research with girls. *Girlhood Studies: An Interdisciplinary Journal, 10*(2), 45–61. https://doi.org/10.3167/ghs.2017.100205

Twenge, J. M., & Park, H. (2017). The decline in adult activities among U.S. adolescents, 1976–2016. *Child Development, 90*(2), 1–17. http://doi.org/10.1111/cdev.12930

Wang, C., & Burris, M. A. (1997). Photovoice: Concept, methodology, and use for participatory needs assessment. *Health Education & Behavior, 24*(3), 369–387. https://doi.org/10.1080/17441692.2021.1928262

War Child Holland. (2012). *Participatory video with children: Facilitators manual*. https://www.eenet.org.uk/resources/docs/PV%20with%20children%20facilitators%20manual.pdf

Wartella, E. A., & Jennings, N. (2000). Children and computers: New technology—Old concerns. *The Future of Children, 10*(2), 31–43. https://doi.org/10.2307/1602688

White, S. A. (Ed.). (2003). *Participatory video: Images that transform and empower*. Sage.

# Part V
# Gamification—Play-Based Learning

# Chapter 20
# A Maths Serious Game for Mobiles: A Study on Design and Development

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**Abstract** Serious games, which are an important and promising alternative to the traditional learning environment, are used in different learning areas. Many empirical studies on serious games as an educational tool have yielded positive results. Games improve students' learning and motivation in the domain of STEM, in particular math. Many math games have been developed to support student learning and to be fun. This research aims to design, develop, and test the usability of a mobile game for primary school students to be used in mathematics education. Usability and user experience are important measures of the quality of software. For serious games to be effective in supporting learning, games must be usable in a way that supports student learning. For this purpose, a 2D mobile game was developed with Unity and usability tests and conducted with 10 primary school students. As a result of the usability test carried out for the current study, the efficiency of the game was evaluated and solutions were considered for the deficiencies identified. Looking at the results, the participants generally liked the game. However, the learnability of our educational game is weak. In addition, the study identifies various limitations of the game and areas for improvement. The game mechanics need to be improved in order to increase efficiency. The memorability level of the game is low. Participants often made the mistake at the start of each level of forgetting to pop at least two balloons. Suggestions on how to overcome these limitations are presented. For future studies, we intend to develop our game in view of the deficiencies highlighted here in order to offer a more efficient and usable learning material. It is hoped that this study will contribute to studies aimed at developing digital educational games by suggesting ideas for reducing usability problems.

**Keywords** Serious games · Educational games · Math games · Usability

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## 20.1 Introduction

This chapter presents a serious game developed for the basic mathematics course, which is an area where STEM students have the most difficulty. In addition, information about the usefulness of the game is provided. The chapter continues with a general introduction, literature review, method findings, discussion, and, finally, conclusions. It is thought that both practitioners and researchers will find the chapter useful.

Over the past few decades, serious games have been used in different topic areas within education. Many empirical studies on serious games as an educational tool have yielded positive results. Although there is no single and definitive definition of serious games, researchers generally define them as games in which the main goal has an educational objective rather than being merely for entertainment. With the popularity of mobile devices, serious games have begun to move onto this platform. This chapter presents the development of a serious game for use in the field of mathematics education, a STEM field, and testing of the usability of the game.

With the widespread use of phones and tablets, the use of mobile devices in the field of education has the potential to meet students' needs. Wartella et al. (2018) point out that in the USA, children under the age of 8 use tablets and smartphones. Mobile devices are often preferred by children due to being cheap and lightweight and having touch screens. The key features of these devices are touch screens, mobility and design, interaction through motion, accessibility, connectivity, and ease of acquisition (Fernández-López et al., 2013). The game presented here was developed in such as way as to take advantage of the features provided by mobile devices.

Despite an increasing national and international focus on science, technology, engineering, and mathematics (STEM) education, K-12 students continue to struggle with STEM content, resulting in very few students being successful in STEM fields, especially science and mathematics. Understanding effective and purposeful teaching and assessment strategies can help teachers provide effective teaching for a wide range of learners (Basham & Marino, 2013). Unfortunately, in PISA results, 50% of students in 24 countries fell below the minimum level of proficiency in mathematics (OECD, 2019). Mathematics is one of the most difficult subjects for students in the STEM disciplines (Topçu & Yıldız Durak, 2019). Serious games can be used to overcome these difficulties (Kiili et al., 2015). One of the main reasons for using games in educational settings is that students find them more interesting and engaging than traditional learning environments (Torbeyns et al., 2015). In addition, games can provide a more active learning experience than the normal classroom setting. The study reported here developed a serious game for use in math education in an attempt to overcome some the problems students face in this topic area. In this chapter, we present the development of the game and the test of its usability.

Educational games can evoke engagement and motivation (Kalogiannakis et al., 2021; Westera, 2019), facilitate student learning (Wouters et al., 2013), and enhance students' problem-solving skills (Sánchez & Olivares, 2011). Games have been developed for most STEM fields. In a review study, Boyle et al. (2016) point out that knowledge acquisition is the main outcome in educational games. They improve student learning and motivation in the domain of STEM. Games can be a tool for facilitating the teaching of science, mathematics, technology, and engineering, i.e. STEM disciplines (Smith, 2020). Serious games may be used to enable students to automate the four processes in math (Fokides, 2018). There are serious games in the field of STEM, especially for students at the beginning of primary school, for example, Monkey Tales and Zeldenrust games (Torbeyns et al., 2015). As the early development of math skills is vital for students' next steps, the game developed in this study focused on 2nd graders in primary school.

For serious games to be effective in supporting learning, games must be appropriately usable. It is important that serious games for educational environments are well designed and have a good level of usability, and care was taken to address these two main features in the development of the game. At this point, the concept of usability should be defined.

Usability is significant in games. With effective menu, settings, and controls, the aesthetics and mechanics of game design is not essential, but it does facilitate smooth playing of the game. Games need to be useable so that the learner can easily master the game controls and focus on the content (Olsen et al., 2011). It is important to examine usability through basic features such as efficiency, playability, and ease of use (Smeddinck, 2016). According to the three-tiered approach put forward by Olsen et al. (2011), it is important to evaluate games not only in terms of general usability but also in terms of playability and learnability. The ISO 9241-11 usability components are effectiveness, efficiency, and satisfaction (Bevan et al., 2016).

One of the most accepted usability evaluation criteria was put forward by Nielsen (2012). Nielsen describes usability as having five components: learnability, efficiency, memorability, errors, and satisfaction. Studies have been carried out using Nielsen's (2012) components. Zaki et al. (2017), for example, examined the usability of the therapeutic game ASAH-I, looking at learnability, efficiency, errors, and satisfaction. Although they identified various problems, its usability was found to be generally suitable. Hussain et al. (2014) tested the usability of JFakih Learning Game for children aged 9–15 using nine criteria, including Nielsen's components. Although they found the game useful and attractive, they also identified areas that needed improvement. Using Nielsen's components, Almeida et al. (2019) examined the usability of the game ALTRIRAS, which was developed for students with autism and recorded generally positive results. Saman et al. (2019) carried out a usability test on a serious game with eight children with hearing loss, considering effectiveness, efficiency, and user satisfaction. They found it had a usability rating of 91.89%. Ismail et al. (2011) studied the usefulness of the game Jelajah with five pre-school children according to effectiveness, efficiency, and satisfaction. Their results showed an overall usability level of 73%. Mahdi (2017) measured the usability of a game developed to teach mathematics to children according to effectiveness, efficacy, and satisfaction and found the game usable. This current study uses Nielsen's (2012) five components to measure usability.

Usability studies have been made for various games. However, more research is needed regarding well-designed serious games in STEM education. The aim of this study is to determine the usability of a mobile serious game developed according to design principles for a 2nd grade primary school mathematics course.

## 20.2 Serious Games

The literature review includes serious games, classification of serious games, the benefits of serious games, mobile serious games, serious games for mathematics, and research in this area. Under this title, general information about serious games and the place of serious games in mathematics from STEM fields are discussed.

Serious games do not have a single and precise definition in the literature and various definitions have been put forward. In general, serious games help the user to reach a desired objective while being entertained.

Prensky (2001) states that games can contribute to young learners' learning processes. The term serious games was first coined by Clark Abt, author of Serious Games (1970), who used war games and simulations in his studies for developing curricula and training. Serious games are often intended for learning (Abt, 1970) and while there is no universally accepted definition of serious games, they are generally accepted as digital games that have at least one purpose in addition to entertainment (Dörner et al., ), which Dörner et al. refer to as "characterizing goals" (Dörner et al., 2016b). For example, if a game aims to teach mathematical concepts besides being entertaining, then it can be called a serious game. Educational games, a subset of serious games, cover many areas from kindergarten to university, individual and collaborative learning, special education, vocational education or on-the-job training, and health games that address mental and physical health (Dörner et al., 2016a). Dörner et al. (2016a) suggest serious games are generally designed for learning in different subjects, for example, mathematics (Barros et al., 2019), science (Baek et al., 2016), and special education (Durkin et al., 2015).

It can be seen from the literature that serious games with potential for education have been developed for different educational levels, in different genres, for different purposes, and for different target audiences. In this context, the varieties and classifications mentioned are also increasing. These details will not be included in this study.

## 20.3 Mobile Serious Games

The features of mobile devices, such as being accessible anywhere and anytime, being personalized, allowing students to learn at their own pace, and allowing easy and fast communication with other people during the learning process, make them suitable in learning environments (Gocheva et al., 2020). Due to their rapidly advancing functionality, mobile devices are frequently used in learning environments (Crompton et al., 2017). Research has shown that students between 8 and 12 years old spend an average of 1 h 17 min per day playing mobile games (Rideout & Robb, 2019).

Sharples and Pea (2014) emphasize that since ancient times, people have learned from the external environment. Mobile devices help to reinforce such learning by enablıng students to learn independently of time and place. With devices being used everywhere, we can say that there are advantages in mobility.

Mobile games, on the other hand, are games defined by the platform. Today, mobile devices that are continually being develop now have the technical capacity to run many mobile games, making them very popular (Laato et al., 2020). The mix of serious games and mobile learning provides advantages for using mobile devices in learning environments (Yallihep & Kutlu, 2020).

The rapid arrival of mobile devices in society has resulted in their convenience for learning environments. At this point, the independence of time and place comes to the fore in the literature, and an emphasis is placed on portability. Lightweight portables are essential devices for serious gaming, given their battery life.

## 20.4 Serious Games for Math

Mathematics is a fundamental discipline and a vital skill the must be acquired for students to succeed in today's society. Individuals who fail in basic mathematics can experience problems in their professional life. Unfortunately, many students in primary and secondary school experience failure and disappointment in mathematics (Huang et al., 2014). However, such weaknesses can be overcome by offering students different approaches, and games provide important support for mathematical development (Kiili et al., 2015). Serious games offer a different alternative in math learning environments and may contribute to students overcoming difficulties in mathematics.

Serious games in mathematics teaching can increase student engagement and motivation and facilitate their learning (Barros et al., 2019). Bakhuys Roozeboom et al. (2017) revealed that serious games lead to higher quality learning and that they have more positive effects compared to the traditional classroom environment. In their review, Hainey et al. (2016) looked at games developed for the field of science. The result of Tokac et al.'s (2019) meta analysis indicate that math learning improves better with games than in the traditional environment. Because of these advantages, serious games can play an important role in improving mathematics learning and students' attitude to mathematics.

Educational games with a teaching purpose as well as being entertaining can be designed to teach mathematics. Such games can work on different devices, such as phones, tablets, and computers, and offer teachers various options for use in teaching mathematics (Pope & Mangram, 2015) (See Fig. 20.1). In fact, teachers' attitudes are very important in the use of such educational applications (Poultsakis et al., 2021). Similarly, parental support is also of undeniable importance (Vaiopoulou et al., 2021).

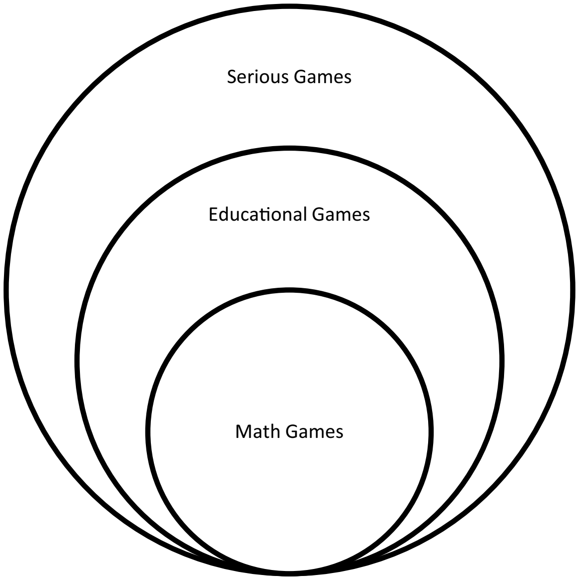


**Fig. 20.1** Subsets of serious games (Laato et al., 2020)

Encouraging teachers and parents to use and encourage the use of these games is an important dimension in using games in mathematics teaching.

### *20.4.1 Available Research on Serious Games for Math*

Many math games have been developed to support student learning and to be fun (Yıldız Durak, 2019). Duffy et al. (2017) developed serious games in arithmetic and geometry for primary school students, subjects that form the basis of STEM education. It was found that test scores were higher for students who played games. Pope and Mangram (2015) developed a game called Wuzzit Trouble, which aimed to improve 3rd grade students' number sense. Of the 59 students in their study, they noted a significant difference in favor of those who played the game over those who did not. van der Ven et al. (2017) tested a mobile game covering addition and subtraction on 103 1st grade students. The calculation efficiency of the students who played the game was found to be high. In Fokides's (2018) study, 201 1st, 4th, and 6th grade primary school students played games that teach basic math skills. The study found that the groups that played games understood the subject better and had increased motivation and interest. The results of empirical studies indicate benefits both academically and in terms of motivation and attitude. Given these results, the study reported here aimed to design and develop a serious game for mathematics lessons.

Hung et al. (2014) tested a game aimed at teaching line symmetry figures on 69 5th grade students. The authors state that it had a positive effect on students' learning, motivation, and self-efficacy in mathematics. Brezovszky et al. (2019) tested the Number Navigation game on 1168 students from 5 to 7th grade. A significant difference was found in favor of the experimental group in terms of adaptive number knowledge and math fluency. Kyriakides et al. (2016) taught algebra to 15 primary school students (10–11 years old) with the mobile game A.L.E.X. They concluded that the students worked willingly and developed positive relationships with mathematics. In their study, Chang et al. (2016) had 107 5th grade students play a game aimed at teaching fractions. The results show that the students' level of participation increased. Rodríguez-Aflecht et al. (2018) tested the game Number Navigation on 212 5th grade students. Although some negative results were recorded over time, they state that most of their students were motivated while playing. The results of these studies are generally positive, particularly on factors such as students' learning, motivation, self-efficacy, and participation, suggesting the use of serious games has promising results.

Robust research on instructional design features to increase the effectiveness of games in learning is scarce (DeLeeuw & Mayer, 2011). As a matter of fact, Papadakis (2021) emphasize that low-quality mobile applications are more common than scientific-based ones. However, the number of studies investigating quality, well-designed serious mobile games is still insufficient. We therefore developed a serious game for math scientifically based on the rigorous pillars of instructional design in an attempt to add to the evidence of the usability of well-designed games. The aim of the study is to reveal the usability of the mobile serious game developed according to design principles for a primary school 2nd grade mathematics course.

## 20.5 Goal—Purpose of the Research

This research aims to design, develop, and test the usability of a mobile game for primary school students to be used in mathematics education. For this purpose, a 2D mobile game was developed and Unity and usability tests were conducted.

## 20.6 Method

### *20.6.1 Research Model*

The study used the evaluation criteria put forward by Nielsen (2012) to evaluate the usability of the developed game. Nielsen describes five components of usability: learnability, efficiency, memorability, errors, and satisfaction. Learnability refers to the ease with which users do tasks they encounter for the first time. While evaluating this criterion, the tendency of the users to use the game, the number of correct transactions in their first use, and the time spent using it are taken into consideration

(Solmaz-Evcil & İslim, 2012). This study determined that the level of difficulty users who encounter the game for the first time face while performing the given tasks and the less support they receive from outside, the better the learnability of the game. Efficiency is the speed with which the user performs the task once they have learnt it, and memorizability is how well the user can use the system again after not using it for a while. When evaluating this criterion, situations such as the time to perform the task, the tasks performed per unit time, the number of aids used, the time spent on aid, and the effort expended are taken into account. The adaptation processes the users go through were examined while they performed the tasks provided in the game. It was determined that the better the speed of adaptation to the game, the better the efficiency of the game. Errors are those made by the user that are solved, and satisfaction is the degree of pleasure the user experiences while using the game. The fewer errors there are in the game, the more confidence the user has in using it (Abrahão et al., 2008). In this study, the errors that occurred while performing the tasks given in the game were observed and at the end of the time given for performing the tasks, users were asked whether they would like to try again and whether or not they liked it. As a result of the observations and the answers given, the error and satisfaction status of the game was evaluated.

Usability research was used in the study. Data obtained through different methods increases the validity and reliability of the results (Yıldırım & Şimşek, 2005). Qualitative methods aim to reveal events in their natural environment, holistically and realistically, using data collection tools such as observation, interview, and document analysis (Yıldırım, 1999). With quantitative methods, phenomena and events are measured and expressed numerically (Büyüköztürk et al., 2008). For this study, participants were provided with the educational game and observed playing it without intervention, using their own technological tools in their home environment. Users are only supported when necessary. The whole process was recorded through Zoom. The participants were also asked whether they liked the game or not, and their opinions were taken into consideration. The participants were evaluated in their performance of the predetermined tasks by examining the records.

### *20.6.2 Participants*

For the educational game, an easily accessible sample group of primary school students was studied. Bevan (2006) recommends eight to ten participants in order to identify all usability problems. The sample in the current study consisted of 10 primary school students, seven girls and three boys. The educational level of the students in the sample were as follows: three primary school 2nd graders, two primary school 3rd graders, three primary school 4th graders, and two secondary school 5th graders. Of the students in the sample, one was seven years old, two were eight years old, two were nine years old, two were ten years old, and three were 11 years old. Information about the students who took part in the usability test is presented in Table 20.1.

**Table 20.1** Participant information

| Participant | Gender | Year of birth | Grade |
|---|---|---|---|
| K1 | F | 2012 | 3 |
| K2 | F | 2013 | 2 |
| K3 | M | 2009 | 5 |
| K4 | F | 2012 | 3 |
| K5 | M | 2010 | 5 |
| K6 | F | 2014 | 2 |
| K7 | M | 2010 | 4 |
| K8 | F | 2011 | 4 |
| K9 | F | 2011 | 4 |
| K10 | F | 2013 | 2 |

### *20.6.3 Data Collection Tool*

Usability tests can be considered as one of the most efficient usability methods recommended for carrying out with real users. According to Nielsen (1993), when testing an interface, it provides real information based on how users use it and what problems they encounter while using it. This usability test was developed by the researchers. Five tasks were used in this test, which cover the mathematics lesson activities presented in the developed game environment. In determining the tasks, the opinions of a mathematics teacher and a field expert experienced in game development were taken. While evaluating the tasks in the usability test, successful and unsuccessful criteria were taken into account. Any user who fulfilled a task completely was considered successful in the task. If the user was not able to perform the requested tasks within the optimum time frame, they were considered unsuccessful. In addition, in the evaluation of usability, the average time spent by the users on the tasks was determined, and the status of the tasks within this optimum time was interpreted. Five tasks were determined by the researchers for usability testing:

1. View the help page.
2. Complete the first level in 90 s.
3. Complete the second level in 90 s.
4. Complete the third level in 120 s.
5. Complete the fourth level in 120 s

Participants were given 60 s for Task 1, 90 s for tasks 2 and 3, and 120 s for tasks 4 and 5. If the participants could not complete the task within the specified time, the task was deemed unsuccessful.

### *20.6.4 Instrument—Procedure*

The first stage in the game development process was to devise a game development design plan. Then, in line with the game scenario, the graphics and visuals were planned and the design phase was carried out using Photoshop. The Unity 2018 2D application was used in this study.

For creating the scene plan and designing and arranging the visuals and objects, color and lighting processes suitable for the age level of the targeted player group were used as much as possible.

In the Unity program, the graphics and objects prepared by adjusting the scene design, camera, and plane positions are placed on the screen. The design process of the game is as follows (Figs. 20.2 and 20.3).

**Four Operations Mathematics Game Design Plan**

1. Game overview

1.1 *Game concept*


**Fig. 20.2** Game flow chart

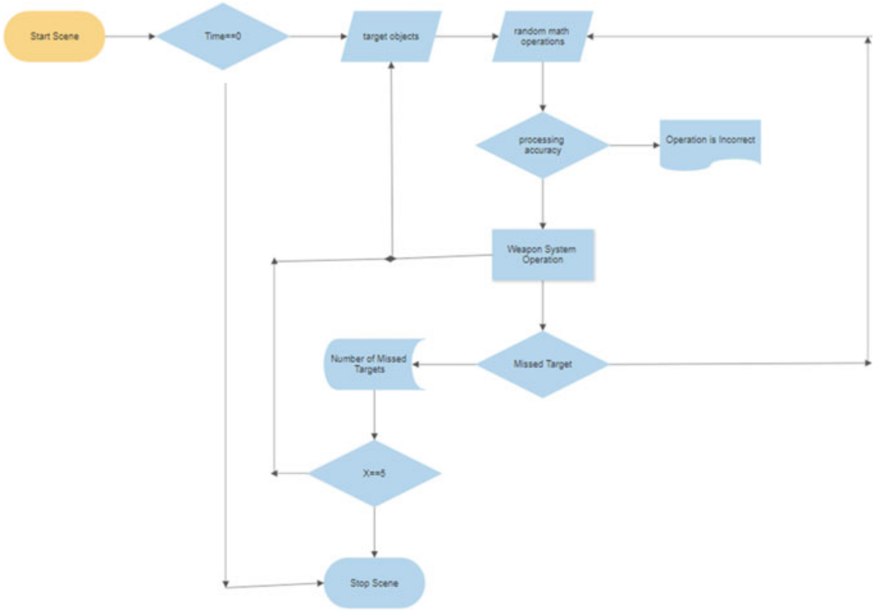


**Fig. 20.3** Game work flow chart

This game is a single player 2D space balloon defense game. The player uses their mathematical knowledge to stop the balloons coming to earth from space. The game was developed with the Unity game engine. It can be played on the web and on Android and IOS operating systems.

1.2 *Game overview*

The game aims to develop players' basic mathematical skills and to enable them to practice mental arithmetic operations in a fun way. Aimed at children of primary school age, it provides practice in mathematical operations in the form of a fun game as an alternative to pen and paper exercises. As the pace of the game increases, players must do the operations faster.

1.3 *Target group*

This game is designed for players over seven years old.

1.4 *Game flow*

The player must burst balloons descending from space and aiming to hit the world. The player must fire a weapon at the level of the balloon. To do this, the player must calculate a mathematical operation under the guns as quickly as possible and enter it into the input box. When they enter the correct answer, the gun fires and the balloon becomes ineffective.

1.5 *Learning objectives*

- Students will be able to perform mental addition.
- Students be able to perform mental subtraction.
- Students will be able to perform mental multiplication.
- Students will be able to perform mental division.

## 2. Game mechanics

### 2.1 *Gameplay*

During the game, players provide the necessary commands using a mouse and keyboard. Players select the weapon they want to use with the mouse and enter the answer using the keyboard. If the action response is wrong, the gun gives a warning and does not fire. When the action answer is correct, the fired weapon moves toward the balloon. If the player can block 100 balloons, they win the game. If five balloons hit Earth, the game is lost.

### 2.2 *Game items*

Balloons: They start falling from a random column at the top of the screen at a random time.

Missile Batteries: This is the area at the bottom of the screen where the operation is asked and the gun is fired.

Missiles: The missile moves from the arsenal to the balloon if the operation is correct.

Health Bar: As balloons hit Earth, the health bar value decreases. When the 5th balloon hits, the health bar is reset.

Time Indicator: This shows the length of time the game has been played and the speed of the game increases at certain time intervals.

Score Indicator: This shows the number of balloons blocked.

Sound Effects and Music: When a weapon is fired, sound plays as the missile moves. When the missile hits the target, an explosion occurs.

Help System: The player is informed about the gameplay game on the login screen. When the operations are carried out incorrectly, the help window opens and the player is supported.

### 2.3 *Game and mechanics*

Playing the Game: During the game, all movements are performed using the mouse and keyboard. The player uses the weapon systems by performing mathematical operations (addition, multiplication, subtraction, and division). A new target appears when a target is hit. Throughout the game, the main character is displayed on the screen in the top perspective.

Win: A game stage is considered won if the player manages to hit the required number of targets within the game time.

Lose: If the player cannot prevent five targets from hitting Earth, the stage is not completed and the game ends.

Movement: A two-dimensional one-way movement method is used in the game. The duration and speed of the movement are related to the player's response time.

Game Elements-Time: The game requires players to complete actions within a certain amount of time. Otherwise, the player loses the game.

2D environments: The game contains objects such as balloons and weapon systems in the space environment.

Maths: The game contains areas in which the player answers questions involving the four basic operations.

3. Technical descriptions

3.1 *Target hardware*

- A computer with standard hardware and the Unity Player plug-in or codec pack installed.
- Standard keyboard and mouse.
- For mobile devices with Android 6 or IOS 8 and above installed.

3.2 *Development software*

- The game is designed using Unity 2017.41f.
- In the preparation of the game, the standard Unity Assests and other necessary assets were downloaded and included in the game library.
- The code block of the game was created with C# programming language and Visual Studio 2017.
- Photoshop CS6 was used for graphics and effects.
- The AfterEfect and Illustrator programs were used for animations and animation effects in the game.

Objects for the game, for example UI objects and prefabs that ensure fluency and continuity, were created and embedded in the scene. The time and position settings of these created objects were made and the motion and animation phases were started. The fictional interaction between the objects was created by designing the relation network between animations and effects. Following the design phase, the code blocks for animating events, flow, and fiction were written, and association processes between the objects that make up the game and the code blocks were established. Once the coding process was complete, necessary adjustments (linear rendering mode, etc.) were made to convert the final output to the most suitable format for different screen sizes. The game was prepared for use on Android and IOS operating systems.

### *20.6.5 Applying Usability Testing*

The usability test was carried out during online meetings with participants held on Zoom. The tasks were given to the participants in order and they were asked to complete a subsequent task on completion of the current task. The researchers did not intervene while the participants were completing the tasks. Finally, the participants were asked their opinions about the game. The meetings were recorded. After application, the video recordings were examined by the researchers and the data was analyzed.

## 20.7 Results

The usability test of the game was applied online to 10 primary school students. Students were asked to complete five tasks in order. The status resulting from the usability test applied online is indicated in Table 20.2 as "+" for those who completed the test and "−" for those who did not.

The results show that the participants read the help page, Task 1, within 60 s. The 1st level addition, Task 2, was completed by the 4th and 5th grade students and the K10 2nd grade student, while the students in other grades and the 5th grade K5 student could not do the addition.

Only the 4th grade students could do the 2nd level multiplication, Task 3. However, two 5th grade students (K3, F5) could not do it either.

Only the 4th grade students and the 2nd grade K10 student could do the 3rd level addition, Task 4. However, two 5th grade students (K3, F5) could not do it either.

Only the 4th grade students K8 and K9 could do the 4th level multiplication, Task 5. However, two 5th grade students (K3, F5) could not do it either.

Table 20.3 shows that Task 1 was successfully performed by all participants. The students who successfully completed the task did so in an average of 6.8 s.

Table 20.4 shows that five participants could not complete Task 2 in the assigned 90-s period. The participants K3, K7, K8, and K9, who successfully completed

**Table 20.2** Participant task completion information

| Participants | Task 1 | Task 2 | Task 3 | Task 4 | Task 5 | Number of successful tasks |
|---|---|---|---|---|---|---|
| K1 | + | − | − | − | − | 1 |
| K2 | + | − | − | − | − | 1 |
| K3 | + | + | − | − | − | 2 |
| K4 | + | − | − | − | − | 1 |
| K5 | + | − | − | − | − | 1 |
| K6 | + | − | − | − | − | 1 |
| K7 | + | + | + | + | + | 5 |
| K8 | + | + | + | + | + | 5 |
| K9 | + | + | + | + | − | 4 |
| K10 | + | + | − | + | − | 3 |
| Number of successful participants | 10 | 5 | 3 | 4 | 2 | |

**Table 20.3** Task 1

| | K1 | K2 | K3 | K4 | K5 | K6 | K7 | K8 | K9 | K10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time to perform the task (Seconds) | 3 | 6 | 2 | 3 | 5 | 5 | 12 | 14 | 10 | 8 |
| Task execution status | + | + | + | + | + | + | + | + | + | + |

**Table 20.4** Task 2

| | K1 | K2 | K3 | K4 | K5 | K6 | K7 | K8 | K9 | K10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time to perform the task (Seconds) | 90 | 90 | 30 | 90 | 90 | 90 | 44 | 52 | 79 | 82 |
| Task execution status | – | – | + | – | – | – | + | + | + | + |

**Table 20.5** Task 3

| | K1 | K2 | K3 | K4 | K5 | K6 | K7 | K8 | K9 | K10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time to perform the task (Seconds) | 90 | G | 90 | 90 | 90 | G | 63 | 61 | 81 | 90 |
| Task execution status | – | – | – | – | – | – | + | + | + | – |

the task, are 4th and 5th grade students and K2 is a 2nd grade student. Successful participants completed the task in an average of 57.4 s.

Table 20.5 shows that five participants could not complete Task 3 in the assigned 90-s period. In fact, two participants skipped the task, stating they did not yet know the multiplication process. K7, K8, and K9 students, who are 4th graders, successfully completed the task. These participants completed the task in an average of 68.3 s.

Table 20.6 shows that six participants could not complete Task 4 in the assigned 120 s. All of the 4th grade students (K7, K8, and K9) and the 2nd grade student (K10) successfully completed the task in an average of 105.7 s.

Table 20.7 shows that six participants could not complete Task 5 in the assigned 120 s. As in the third task, two participants skipped the task because they did not know the multiplication process. Only K7 and K8 students were able to successfully

**Table 20.6** Task 4

| | K1 | K2 | K3 | K4 | K5 | K6 | K7 | K8 | K9 | K10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time to perform the task (Seconds) | 120 | 120 | 120 | 120 | 120 | 120 | 96 | 102 | 110 | 115 |
| Task execution status | – | – | – | – | – | – | + | + | + | + |

**Table 20.7** Task 5

| | K1 | K2 | K3 | K4 | K5 | K6 | K7 | K8 | K9 | K10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Time to perform the task (Seconds) | 120 | G | 120 | 120 | 120 | G | 102 | 108 | 120 | 120 |
| Task Execution Status | – | – | – | – | – | – | + | + | – | – |

**Table 20.8** Mann–Whitney U test results of task performance by gender

| | Task 1 | Task 2 | Task 3 | Task 4 | Task 5 |
|---|---|---|---|---|---|
| Mann–Whitney U | 10,5 | 8 | 10 | 9,5 | 8,5 |
| Wilcoxon W | 16,5 | 36 | 38 | 15,5 | 36,5 |
| Z | 0 | −0,655 | −0,143 | −0,267 | −0,655 |
| Asymp. Sig. (2-tailed) | 1 | 0,513 | 0,886 | 0,789 | 0,513 |

Descriptives

| | Gender | Mean rank | Sum of ranks |
|---|---|---|---|
| Task 1 | Female | 5.5 | 38.5 |
| | Male | 5.5 | 16.5 |
| Task 2 | Female | 5.14 | 36 |
| | Male | 6.33 | 19 |
| Task 3 | Female | 5.43 | 38 |
| | Male | 5.67 | 17 |
| Task 4 | Female | 5.64 | 39.5 |
| | Male | 5.17 | 15.5 |
| Task 5 | Female | 5.21 | 36.5 |
| | Male | 6.17 | 18.5 |

complete this task. Those students who successfully completed the task did so in an average of 105 s.

In this study, the Mann–Whitney U test was conducted to determine differences between user task times and successful task completion by gender.

Table 20.8 shows that no significant differences were found between the task performance of male and female users from Task 1 to Task 5. Although there is no statistically significant difference, the descriptive statistics show that the mean rank of male and female students are equal regarding achievement of Task 1. For Task 2, Task 3, and Task 5, the male student average is higher, while in Task 4, the female student average is higher.

Table 20.9 shows no significant differences were found between the task performance periods of male and female users from Task 1 to Task 5. Although no statistically significant difference could be found, the descriptive statistics show that the time performing Task 1, Task 2, and Task 4 was lower for male students than female students. Female students performed Task 3 and Task 5 faster.

## 20.8 Discussion-Conclusion and Recommendations

The aim of this study was to design, develop, and test the usability of a mobile game for primary school students for use in mathematics education. For this purpose, a 2D

**Table 20.9** Mann–Whitney U test results of task duration by gender

| | Task 1 | Task 2 | Task 3 | Task 4 | Task 5 |
|---|---|---|---|---|---|
| Mann–Whitney U | 8,5 | 5 | 7 | 10 | 9 |
| Wilcoxon W | 14.5 | 11 | 35 | 16 | 37 |
| Z | −0.459 | −1.337 | −0.854 | −0.128 | −0.387 |
| Asymp. Sig. (2-tailed) | 0.646 | 0.181 | 0.393 | 0.898 | 0.699 |

| | Gender | Mean rank | Sum of ranks |
|---|---|---|---|
| Task 1 | Female | 5.79 | 40.5 |
| | Male | 4.83 | 14.5 |
| Task 2 | Female | 6.29 | 44 |
| | Male | 3.67 | 11 |
| Task 3 | Female | 5 | 35 |
| | Male | 6.67 | 20 |
| Task 4 | Female | 5.57 | 39 |
| | Male | 5.33 | 16 |
| Task 5 | Female | 5.29 | 37 |
| | Male | 6 | 18 |

mobile game was developed with Unity and usability tests conducted with 10 primary school students. Usability and user experience are important measures of the quality of software. In the field of education, these quality characteristics are necessary to ensure an appropriate teaching process (Salas et al., 2019; Yildiz Durak, 2021). In order to provide a positive gaming experience for users, a game must be usable (Law & Sun, 2012).

According to Nielsen (2012), usability is a quality feature that evaluates the ease of use of application interfaces. It is defined by five components: learnability, efficiency, memorability, errors, and satisfaction.

Learnability: This can be expressed as the ease of performing basic tasks when users first encounter the design (Nielsen, 2012). Olsen et al. (2011) suggest that insufficient usability in games negatively affects students' learning.

Looking at the game designed for this study in terms of learnability, although participants acheived a 100% success rate for Task 1, their success rate for the other four tasks did not exceed 50%. It can therefore be concluded that the learnability of our educational game is weak. The average learnability of the game in their study was 3.6 out of 5. The reason was that the children were not familiar with the game at their first attempt. They point out that the children got accustomed to it afterwards. Zaki et al. (2017) reveal that more than half of the games they looked at were completed in a short time by users and that learnability was generally good. In contrast, the learnability score was high in Almeida et al.'s (2019) game study. Their observations suggest that this situation was mostly caused by insufficient time being given to the users for the game tasks. It is expected that the success rate will increase by increasing the duration of each of the tasks. In addition, the reason for the low level of the four tasks in their study can be attributed to the participants encountering unfamiliar concepts/topics (Sloan & Horton, 2019).

Efficiency: This is how quickly users are able to perform tasks after learning the pattern (Nielsen, 2012). In the test conducted according to the execution time of the determined tasks, only 20% of the participants were able to complete all the tasks on time. This suggests that the game needs to be improved in terms of efficiency. Hussain et al. (2014) scored an efficiency of 4 out of 5, although they did find some problems.

Game mechanics relate to the rule design and coding structure of a game (Demirbaş, 2020). In this study, participants often lost time waiting for the required numbers and failed due to time constraints. In this case, it was concluded that the game should be improved in terms of game mechanics in order to increase efficiency.

Memorability: Users should not have to re-learn how to use an application when they return to it after a while (Nielsen, 2012). If the interface design of different game scenes is consistent, users will quickly remember the system usage functionality (İşleyen et al., 2014). The levels in the current game (except for Task 1) were designed with similar features in terms of usage and game rules. Tasks 2 and 4 cover addition while Tasks 3 and 5 cover multiplication. This allows participants to play the game at all levels without having to learn new features. However, in light of the simple to complex principle, the tasks are similar but are designed in a structure that becomes increasingly difficult. This suggests that the memorability level of the game is low. However, this situation could be due to the increasingly difficult structure of the game. This can be improved by including more familiar design elements as these can increase memorability (Sloan & Horton, 2019).

Errors: This is about the number of mistakes that users make while using the application and their ability to correct them (Nielsen, 2012). The mistake usually made by participants when they started each level was that they forgot to pop at least two balloons. Providing feedback to users following mistakes can reduce the error rate. Similarly, in Zaki et al.'s study (2017), minimal errors were made in games, except an error of 50% in one game. Likewise, Hussain et al. (2014) observed the children's errors and stated a game was usable.

Satisfaction: This is the pleasure users experience while using the application (Nielsen, 2012). In the current study, once the game was over, participants were asked whether they liked the game or not. The positive responses received from all participants suggests they generally likes the game. Similarly, Hussain et al. (2014) recorded satisfaction at 4.2 and state that it was generally appreciated. One usability study recorded satisfaction at 97% (Saman et al., 2019) while another recorded it at 95% (Mahdi, 2017). Zaki et al. (2017) state that most users were satisfied with the games they looked at, but a few users were not satisfied with the games' slow response. For users to enjoy playing a game and for the game to hold their interest, users must be able to complete the game and their achievements must be rewarded (AlDakhil et al., 2019). The current study concludes that in order to increase user satisfaction, the difficulty level of the game needs to be reduced and a reward system added.

Carrying out a usability test during the development of learning materials can reduce usability problems and increase the quality and efficiency of the system (Chang & Johnson, 2021). As a result of the usability test carried out for the current study, the efficiency of the game was evaluated and solutions were considered for the deficiencies identified.

The results of the study show that gender did not lead to a significant difference in the performance of learning tasks or on the duration of their execution. It can therefore be said that it is not important to use gender-specific designs in order to increase the effectiveness of serious games. Considering the learnability, efficiency, memorability, errors, and satisfaction criteria, it is thought that the learnability of the Unity-based game developed in the context of this study needs to be improved and amended in terms of efficiency, but the problems experienced regarding time are due to the fact that the users explored the game and were distracted by non-task objects during the tasks. When designing serious games, therefore, attention needs to be paid to the use of objects that will distract the user's attention from the learning content. In addition, the content of the task to be presented may need to be presented to students in a simple way. Memorability, bugs, and satisfaction are other aspects that need improvement in this game. In this context, it is important that the design used in the presentation of the content is as simple and plain as the teaching content of the game. A further consideration is that special attention should be paid to configuring the difficulty level of the game in order to increase user satisfaction. In addition, it has been observed that a well-structured reward system in serious games has positive contributions to the usability criteria of the game.

Although this study makes a valuable contribution to the literature and practice field of the development and usability of serious games developed for primary school mathematics courses, it does have some limitations. Our research only conducted a user-based usability study, the game was developed for one particular subject, math, and the study focused purely on second grade students. The study did not measure the effectiveness of the game with an experimental design. For future studies, we intend to develop our game in view of the deficiencies highlighted here and offer a more efficient and more usable learning material. It is also possible that the topics covered by the game can be increased in future studies and the game can be developed for different educational levels. Experimental studies could be conducted to measure the effectiveness of the game. Comparative studies could be conducted with large groups. The number of levels in the game can be increased according to the classes and longitudinal studies can be done. Usability studies can be extended using eye tracking. It is hoped that this study will contribute to studies aiming to develop digital educational games by suggesting ideas for reducing usability problems.

## References


Abt, C. C. (1970). *Serious games*. Viking.

Abrahão, S., Cachero, C., & Matera, M. (2008). Web usability and accessibility. *Journal of Web Engineering, 7*(4), 257–257.

AlDakhil, S., Taleb, E. A., Ghamlas, M. A., & Al-Megren, S. (2019). Assessing the usability of a tangible educational game for children [Conference presentation]. In *2019 2nd International conference on computer applications & ınformation security (ICCAIS)* (pp. 1–5).

Almeida, L. M., Silva, D. P. D., Theodório, D. P., Silva, W. W., Rodrigues, S. C. M., Scardovelli, T. A., & Bissaco, M. A. S. (2019). ALTRIRAS: A computer game for training children with autism spectrum disorder in the recognition of basic emotions. *International Journal of Computer Games Technology, 2019* (4384896), 16 p. https://doi.org/10.1155/2019/4384896

Baek, S., Park, J. Y., & Han, J. (2016). Simulation-based serious games for science education and teacher assessment. *International Journal of Serious Games, 3*(3), 59–66.

Bakhuys Roozeboom, M., Visschedijk, G., & Oprins, E. (2017). The effectiveness of three serious games measuring generic learning features. *British Journal of Educational Technology, 48*(1), 83–100.

Barros, C., Carvalho, A. A., & Salgueiro, A. (2019). The effect of the serious game Tempoly on learning arithmetic polynomial operations. *Education and Information Technologies*, *1*(13).

Basham, J. D., & Marino, M. T. (2013). Understanding STEM education and supporting students through universal design for learning. *Teaching Exceptional Children, 45*(4), 8–15.

Bevan, N. (2006). Practical issues in usability measurement. *Interactions, 13*(6), 42–43.

Bevan, N., Carter, J., Earthy, J., Geis, T., & Harker, S. (2016, July). New ISO standards for usability, usability reports and usability measures. In *International conference on human-computer ınteraction* (pp. 268–278). Springer.

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., … Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education, 94*, 178–192.

Brezovszky, B., McMullen, J., Veermans, K., Hannula-Sormunen, M. M., Rodríguez-Aflecht, G., Pongsakdi, N., & Lehtinen, E. (2019). Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge. *Computers & Education, 128*, 63–74.

Büyüköztürk, Ş., Kılıç-Çakmak, E., Akgün, Ö. E., Karadeniz, Ş., & Demirel, F. (2008). *Bilimsel Araştırma Yöntemleri*. Pegem A Yayıncılık.

Chang, M., Evans, M. A., Kim, S., Norton, A., Deater-Deckard, K., & Samur, Y. (2016). The effects of an educational video game on mathematical engagement. *Education and Information Technologies, 21*(5), 1283–1297.

Chang, C. C., & Johnson, T. (2021). Integrating heuristics and think-aloud approach to evaluate the usability of game-based learning material. *Journal of Computers in Education, 8*(1), 137–157.

Crompton, H., Burke, D., & Gregory, K. H. (2017). The use of mobile learning in PK-12 education: A systematic review. *Computers & Education, 110*, 51–63.

DeLeeuw, K. E., & Mayer, R. E. (2011). Cognitive consequences of making computer-based learning activities more game-like. *Computers in Human Behavior*, *27*(5).

Demirbaş, Y. (2020). Dijital Oyunlarda Oynanış ve Anlatı İlişkisi: DayZ Oyunu ve Village Topluluğu. *Galatasaray Üniversitesi İletişim Dergisi, 32*, 80–107.

Dörner, R., Göbel, S., & Kickmeier-Rust, M. (2016a). Introduction to the GI-Dagstuhl book on entertainment computing and serious games. In *Entertainment computing and serious games* (pp. 1–16). Springer.

Dörner, R., Göbel, S., Effelsberg, W., Wiemeyer, J. (2016b). *Serious games: Foundations, concepts and practice*. Springer.

Duffy, S., Price, S., Volpe, G., Marshall, P., Bianchi-Berthouze, N., & Cappagli, G. (2017). WeDraw: Using multisensory serious games to explore concepts in primary mathematics. In *Proceedings of the 13th ınternational conference on technology in mathematics teaching* (ICTMT) (p. 13).

Durkin, K., Boyle, J., Hunter, S., & Conti-Ramsden, G. (2015). Video games for children and adolescents with special educational needs. *Zeitschrift Fur Psychologie, 221*(2), 79–89.

Fokides, E. (2018). Digital educational games and mathematics: Results of a case study in primary school settings. *Education and Information Technologies, 23*(2), 851–867.

Fernández-López, Á., Rodríguez-Fórtiz, M. J., Rodríguez-Almendros, M. L., & Martínez-Segura, M. J. (2013). Mobile learning technology based on iOS devices to support students with special education needs. *Computers & Education, 61*, 77–90.

Gocheva, M., Somova, E., Angelova, V., Kasakliev, N. (2020, March). Types of mobile educational games for children in primary school. In *14th International technology, education and development conference*, Valencia, March 2020. https://doi.org/10.21125/inted.2020.0698

Hainey, T., Connolly, T. M., Boyle, E. A., Wilson, A., & Razak, A. (2016). A systematic literature review of games-based learning empirical evidence in primary education. *Computers & Education, 102*, 202–223.

Huang, Y. M., Huang, S. H., & Wu, T. T. (2014). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Educational Technology Research and Development, 62*, 187–207. https://doi.org/10.1007/s11423-013-9315-4

Hung, C.-M., Huang, I., & Hwang, G.-J. (2014). Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. *Journal of Computers in Education, 1*, 151–166. https://doi.org/10.1007/s40692-014-0008-8

Hussain, A., Mutalib, N. A., & Zaino, A. (2014, November). A usability testing on JFakih Learning Games for hearing impairment children. In *The 5th ınternational conference on ınformation and communication technology for the muslim world (ICT4M)* (pp. 1–4). IEEE.

Ismail, M., Diah, N. M., Ahmad, S., Kamal, N. A. M., & Dahari, M. K. M. (2011). Measuring usability of educational computer games based on the user success rate. In *2011 International symposium on humanities, science and engineering research* (pp. 56–60). IEEE.

İşleyen, F., Gülkesen, K. H., Cinemre, B., Samur, M. K., Zayim, N., & Kaya, S. S. (2014, January). Evaluation of the usability of a serious game aiming to teach facial expressions to schizophrenic patients. *MIE*, 662–666.

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. I. (2021). Gamification in science education. A systematic review of the literature. *Education Sciences*, *11*(1), 22.

Kiili, K., Devlin, K., & Multisilta, J. (2015). Is game-based math learning finally coming of age? *International Journal of Serious Games, 2*(4), 1–4.

Kyriakides, A., Meletiou-Mavrotheri, M., & Prodromou, T. (2016). Mobile technologies in the service of students' learning of mathematics: The example of game application A.L.E.X. in the context of a primary school in Cyprus. *Mathematics Education Research Journal*, *28*(1), 53–78.

Laato, S., Lindberg, R., Laine, T. H., Bui, P., Brezovszky, B., Koivunen, L., & Lehtinen, E. (2020, June). Evaluation of the pedagogical quality of mobile math games in app marketplaces. In *2020 IEEE International conference on engineering, technology and ınnovation (ICE/ITMC)* (pp. 1–8). IEEE.

Law, E. L. C., & Sun, X. (2012). Evaluating user experience of adaptive digital educational games with activity theory. *International Journal of Human-Computer Studies, 70*(7), 478–497.

Mahdi, S. M. (2017). *Educational mobile game design for children learning mathematics*. Doctoral dissertation, Universiti Utara Malaysia.

Nielsen, J. (1993). *Usability engineering*. Academic Press.

Nielsen, J. (2012). *Usability 101: Introduction to usability* [Online: https://www.nngroup.com/articles/usability-101-introduction-to-usability/] Accessed February 7, 2021.

OECD. (2019). *PISA 2018 results: Combined executive summaries*. www.oecd.org/pisa/Combined_Executive_Summaries_PISA_2018.pdf

Olsen, T., Procci, K., & Bowers, C. (2011, July). Serious games usability testing: How to ensure proper usability, playability, and effectiveness. In *International conference of design, user experience, and usability* (pp. 625–634). Springer.

Papadakis, S. (2021). Advances in mobile learning educational research (AMLER): Mobile learning as an educational reform. *Advances in Mobile Learning Educational Research, 1*(1), 1–4.

Pope, H., & Mangram, C. (2015). Wuzzit trouble: The influence of a digital math game on student number sense. *International Journal of Serious Games*, *2*(4).

Poultsakis, S., Papadakis, S., Kalogiannakis, M., & Psycharis, S. (2021). The management of digital learning objects of natural sciences and digital experiment simulation tools by teachers. Advances in mobile learning. *Educational Research, 1*(2), 58–71.

Prensky, M. (2001). *Digital game-based learning*. McGraw-Hill.

Rideout, V., & Robb, M. B. (2019). *The common sense census: Media use by tweens and teens.* Common Sense Media.

Rodríguez-Aflecht, G., Jaakkola, T., Pongsakdi, N., Hannula-Sormunen, M., Brezovszky, B., & Lehtinen, E. (2018). The development of situational interest during a digital mathematics game. *Journal of Computer Assisted Learning, 34*(3), 259–268.

Salas J. et al. (2019). Guidelines to evaluate the usability and user experience of learning support platforms: A systematic review. In P. Ruiz & V. Agredo-Delgado (Eds.), *Human-computer ınteraction. HCI-COLLAB 2019*. Part of communications in computer and ınformation science book series, vol. 1114. Springer. https://doi.org/10.1007/978-3-030-37386-3_18

Saman, F. I., Shariff, N. F. M., & Nasaruddin, N. I. S. (2019). i-Sign: Sign language learning application via gamification. *Asian Journal of University Education, 15*(3), 187–197.

Sánchez, J., & Olivares, R. (2011). Problem solving and collaboration using mobile serious games. *Computers & Education, 57*(3), 1943–1952.

Solmaz Evcil, E., & İslim, Ö. F. (2012). Kullanılabilirlik Kavramı ve Kullanılabilirlik Ölçümleri. In *6th ICITS 2012 Conference*.

Sharples, M., & Pea, R. (2014). Mobile learning. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 501–521). Cambridge University Press.

Sloan, D., & Horton, S. (2019). Usability, universal usability, and design patterns. *Web Accessibility* (pp. 445–460). Springer.

Smeddinck, J. D. (2016). Games for health. *Entertainment computing and serious games* (pp. 212–264). Springer.

Smith, H. (2020). *Learning through games: How math games can enhance education.* Doctoral dissertation. Worcester Polytechnic Institute.

Tokac, U., Novak, E., & Thompson, C. G. (2019). Effects of game-based learning on students' mathematics achievement: A meta-analysis. *Journal of Computer Assisted Learning, 35*(3), 407–420.

Topçu, A., & Yıldız Durak, H. (2019). PISA Sonuçlarına göre Öğretmen STEM Eğitimlerinin Değerlendirilmesi. In *VIth International Eurasian Educational Research Congress*. June 19–22, 2019, Ankara, Turkey.

Torbeyns, J., Lehtinen, E., & Elen, J. (2015). Describing and studying domain-specific serious games: Introduction. *Describing and studying domain-specific serious games* (pp. 1–6). Springer.

Vaiopoulou, J., Papadakis, S., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Parents' perceptions of educational apps use for kindergarten children: development and validation of a new instrument (PEAU-p) and exploration of parents' profiles. *Behavioral Sciences, 11*(6), 82.

van der Ven, F., Segers, E., Takashima, A., & Verhoeven, L. (2017). Effects of a tablet game intervention on simple addition and subtraction fluency in first graders. *Computers in Human Behavior, 72*, 200–207.

Wartella, E. A., Lovato, S. B., Pila, S., Lauricella, A. R., Echevarria, R., Evans, J., & Hightower, B. (2018). Digital media use by young children: Learning, effects, and health outcomes. In *Child and Adolescent Psychiatry and the Media* (pp. 173–186). Elsevier.

Westera, W. (2019). Why and how serious games can become far more effective: Accommodating productive learning experiences, learner motivation and the monitoring of learning gains. *Journal of Educational Technology & Society, 22*(1), 59–69.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*, 249–265.

Yallihep, M., & Kutlu, B. (2020). Mobile serious games: Effects on students' understanding of programming concepts and attitudes towards information technology. *Education and Information Technologies, 25*(2), 1237–1254.

Yıldırım, A., & Şimşek, H. (2005). *Sosyal bilimlerde nitel araştırma yöntemleri*. Seçkin Yayıncılık.

Yıldırım, A. (1999). Nitel Araştırma Yöntemlerinin Temel Özellikleri ve Eğitim Araştırmalarındaki Yeri ve Önemi. *Eğitim Ve Bilim, 23*(112), 7–17.

Yıldız Durak, H. (2019). Matematik Öğretmenliği Öğretmen Adaylarının Oyun Algıları ve Oyunların Matematik Eğitimine Entegrasyonu ile İlgili Görüşlerinin İncelenmesi. In *ERPA International congresses on education 2019*, June 19–22, 2019. Sakarya, Turkey.

Yildiz Durak, H. (2021). Lisansüstü Öğrencilerinin Unity ile Oyun Geliştirme Deneyimleri. 9. Uluslararası Öğretim Teknolojileri ve Öğretmen Eğitimi Sempozyumu, 17–19 Kasım 2021, Karadeniz Teknik Üniversitesi, Trabzon.

Zaki, N. A. A., Wook, T. S. M. T., & Ahmad, K. (2017, November). A usability testing of ASAH-/for children with speech and language delay. In *2017 6th International conference on electrical engineering and ınformatics (ICEEI)* (pp. 1–6). IEEE.

# Chapter 21
# Digital Games for STEM in Early Childhood Education: Active Co-playing Parental Mediation and Educational Content Examination

**Ali İbrahim Can Gözüm**

**Abstract** This study aimed to examine digital games with STEM content played by children aged 60–72 months from an educational point of view and determine how parents use the active co-playing strategy in playing these games. The study was carried out using a basic qualitative research design due to the nature of qualitative research. The participants in the study were volunteers and were selected according to specific criteria using purposeful sampling. The survey and questionnaire forms developed by (Gözüm and Kandır in Educ Inf Technol 26:3293–3326, 2021) were used in the study. Data on digital games were collected using the document analysis technique. Content analysis was used to determine the content of digital games. In contrast, descriptive analysis was used for the parents' data for the active co-playing strategy. Expert review was used to assess the reliability of the themes obtained from descriptive and content analysis. Themes were determined using the codes and categories derived from content analysis and expert review. According to the study results, it was concluded that the children of the parents who use the active co-playing strategy played at least one STEM game. These results also show which digital games with STEM content support the development of children's skills and explain how parents use the active co-playing strategy. Due to the nature of qualitative research, there are limitations to making generalizations in this study. Important suggestions have been made for parents, researchers, and digital game developers.

**Keywords** Parental mediation · Active-co playing · Digital game · STEM

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## 21.1 Introduction

An increase in mobile apps is being observed nowadays due to the rise in computer-based mobile devices with touch screens. While the rise of mobile applications is evident in all areas of life, many mobile apps in the field of education claim to have educational content (Zaranis et al., 2013). Children in early childhood can use touch-screen tablets and phones with ease, leading to a significant share of the mobile market being dedicated to children. Mobile apps developed for children can be set in different educational areas such as science, mathematics, early literacy, art, the environment, and STEM (Papadakis & Kalogiannakis, 2020). While some of the developed mobile applications do carry educational content, it has been determined that some of them do not and are apps that are purely for entertainment (Papadakis & Kalogiannakis, 2017). Parents and teachers who want to support children's development and learning have essential responsibilities. While the debate over mobile apps in early childhood education classrooms continues, children can use mobile apps at home. Parents have duties critical to fulfilling when their children use mobile apps at home. They use parental mediation strategies when their children use mobile apps. They can play the digital games children play and use the "active co-playing mediation" strategy by talking about these digital games with their children (Gözüm & Kandır, 2021). In this way, parents learn the contents of the digital games children play and can thus choose digital games to support their children's education. Parents prefer mobile apps with the STEM content mentioned in early childhood education to support their children. They may want their children to use these apps. This study focuses on the STEM content mobile apps chosen for their children by parents who use the "active co-playing mediation" strategy. The study aims to investigate the criteria parents use when choosing STEM content apps for their children, whether or not the mobile apps are suitable for STEM content, and how they use the active co-playing strategy when their children use mobile apps. Therefore, under the subheading "literature review," the study's importance and questions will be explained by discussing STEM in Early Childhood Education, Mobile Apps for STEM, and Parental Mediation.

## 21.2 Literature Review

### *21.2.1 STEM in Early Childhood Education*

STEM is an acronym made up of the first letters of Science, Technology, Engineering, and Mathematics. Structurally speaking, the word STEM expresses a learning approach resulting from the interdisciplinary interaction of Science, Technology, Engineering, and Mathematics knowledge, skills, and understanding (Bilton & Watts, 2019; Gonzalez & Kuenzi, 2012). The most crucial point that should not be overlooked in the STEM learning approach is that merging different disciplines houses twenty-first century man's skills, such as creativity, problem-solving, and technology literacy, without focusing solely on knowledge (Charette, 2014; Yelland & Gilbert, 2018). However, debates continue over whether or not STEM content in early childhood is intended for children, and it is essential because it provides the basic skills that children need to acquire in early childhood in their future lives.

One aspect of this debate is that STEM education is subject to content. Teaching basic concepts to children is not appropriate to early childhood education (Gartell, 2016). Another aspect of the discussion is that although science and mathematics applications can be found in early childhood, engineering and technology are not suitable given the developmental characteristics of children (Sarama et al., 2018). However, it is accepted that STEM education should be implemented in early childhood to focus on children's conscious perception and awareness instead of teaching them subjects. For example, experimenting with certain stimuli so that children can experience gravity without teaching them the laws of gravity (Gibson & Pick, 2000). In this respect, STEM supports perception, thinking, and action through daily life experiences rather than teaching certain concepts or laws to children. In this context, when children act by perceiving the functions of the systems in the world and by thinking with an understanding of STEM, this can make for research that develops a basic level of scientific knowledge (Moomaw, 2013). From this perspective, STEM education is vital for children in early childhood.

It can be said that the teacher and the education program are two critical factors in providing quality STEM education in early childhood. Two priority factors expected here are for teachers to have high self-efficacy concerning STEM applications and an ability to adapt technology to fit the class environment. Therefore, there is a need for early childhood educators to receive technology training for STEM in the pre-service period (Estapa & Tank, 2017; Looi et al., 2011). Teachers apply STEM practices in early childhood education based on the education program, which is also very important (Margot & Kettler, 2019). The use of smartphones, tablets, digital audio and video recorders, and cameras provides essential opportunities for STEM education (Kallogiannakis & Papadakis, 2020). STEM stands out in the technology industry, and it allows children with active learning and learning across different disciplines to develop their academic and professional skills (Papadakis, 2018a). Accordingly, mobile apps for the STEM education of children have been developed by technology investors, and the use of mobile apps has increased significantly with children using smartphones and tablets. Teachers are responsible for implementing STEM applications in classrooms, while parents are responsible for this at home. Based on this, mobile apps developed for STEM are explained first, followed by the literature on parental mediation.

### *21.2.2 Mobile Applications for STEM*

Mobile apps for STEM education have the potential to simplify teaching methods (Sung et al., 2016). Using mobile apps for STEM applications makes children's learning mobile and takes them out of traditional classrooms (Mundie & Hooper, 2014). According to Aladé et al. (2016), digital technologies such as tablets and smartphones with touch screens can support children's development in STEM education. Using tablets or phones to take photographs, watch videos and simulations, or play digital games can develop scientific understanding and discourse, which is the purpose of STEM for children (Sharrifnia et al., 2015). According to Sherry (2015), STEM-content educational digital games can instill an understanding of STEM in early childhood children by attracting their attention.

By playing digital games in the science, mathematics, technology, and engineering disciplines suitable for the development of children in early childhood, their experience can be increased, and problem-solving and concept development, which is the aim of STEM, can be achieved (Papadakis, 2018b; Papadakis et al., 2017a, 2017b). In this regard, the content of digital apps, the subject of this study, will be discussed by defining quality STEM content in early childhood that will support children's skill and concept development. Quality STEM content in digital apps has been examined in the literatüre. When the first concept of science is discussed in STEM content, it consists of life sciences, Earth and space sciences, and physical sciences (Bredekamp, 2015). The content of life sciences deals with living properties, cycles of life, and environmental content. It enables creatures' growth cycles in life, the characteristics of plants and animals to be observed, and their needs in life to be understood. Children consider plants and animals as living beings (Bredekamp, 2015; MacDonals, 2015; Moomaw, 2013). Earth and space sciences contain accurate observations from the child's immediate environment to far away, encompassing the movements of the Earth, the sun, and the moon and the natural phenomena caused by their positions concerning one another. In this regard, children can observe environmental phenomena and situations resulting from the Earth and the sun, such as the seasons, night and day, shadows, reflection, and refraction (Bredekamp, 2015; MacDonald, 2015; Moomaw, 2013). The physical sciences include the properties of matter and basic information about what is meant by dynamic and static (Bredekamp, 2015). The physical sciences allow one to observe the gravitational effects of objects and how magnetic objects interact (MacDonald, 2015; Moomaw, 2013). Concepts such as weight, force, heat, lift, thrust, floating, and sinking are examined (Moomaw, 2013).

On examination of the technology discipline in STEM, it is seen that it can be used as a tool to help learn the other STEM disciplines of science, mathematics, and engineering instead of simply presenting content to children in early childhood (Early STEM Matters, 2017). Using digital apps, children can learn to code directly related to STEM disciplines and develop programming skills using computers and tablets (Rushkoff, 2010). For a child to make a robot move, he needs to learn how to program that robot's instructions. When children do this coding, they can use counting processes and location-direction outcomes for the robot's movement mechanism (Bers, 2010). This is an example of technology as an intermediary in using science and technology content in STEM.

Examining the engineering discipline in STEM education, Lange et al. (2019) argue that this builds and improves children's ideas by modeling them on structures. Children can design their models or systems in early childhood by using building materials in digital apps. These design apps help children understand the content of science concepts such as gravity and balance, and they support the development of math skills such as counting, painting, and part-whole relationships (Lange et al., 2019; Texley & Ruud, 2018). In engineering applications, the building construction models that children will make in the classroom with blocks are reflected in digital apps. However, construct modeling in early childhood may be limited to materials to support the children's inventions (Clements & Sarama, 2016). In this context, digital apps increase the possibilities for children to use materials in different areas, shapes, and sizes to design construction models. This provides opportunities for children to develop visual-spatial skills such as area, shape, and size (MacDonald et al., 2015).

When the STEM education discipline of mathematics is examined, content such as comparison, classification, ordering, counting, geometry, graphics (reading, creating, interpreting), and measurement comes to the fore in early childhood (Clements & Sarama, 2016). Using mathematics for STEM education, children can perform operations such as counting and operations, measuring the length and area of small objects, comparing objects as being more or less, and calculating part-whole (dividing) (Moomaw, 2013). When children are doing operations for STEM, they can do basic addition, subtraction, and problem-solving (Bredekamp, 2015).

In the early years, children can be provided with the opportunity to develop their science, engineering, and mathematics skills by using mobile apps with quality STEM content according to the disciplines defined above for STEM (Kalogiannakis & Papadakis, 2020). However, for children to benefit from this opportunity, they need to use quality STEM mobile apps. The study conducted by Gözüm and Kandır (2021) reported that while some digital games do have educational content, some do not and even have violent content. Therefore, the digital games that easily attract children's attention must have educational content that includes STEM. It has been determined that many mobile apps that claim to be educational are not educational in content. This being so, this study asks: "Do the digital games played by children have quality STEM educational content?" The conclusion made by Gözüm and Kandır (2021) is beneficial in answering this research question. It has been stated that children play digital games possessing educational content when parents consciously use mediation strategies. The results of the study show that children of parents who use the active co-play mediation strategy benefit positively from digital games possessing educational content. The digital market is filled with countless iOS and Android apps.

In short, in the digital market, parents play a critical role in choosing educational games for children and supporting the development of these games. However, only after developing apps that attract children's attention and improve their problem-solving skills can their development and academic achievement be supported (Papadakis et al., 2017a; 2017b). It is crucial to determine what parents who fulfill their responsibilities think about digital apps with STEM content. In this context, according to the research results of Gözüm and Kandır (2021), parents who use the active co-play mediation strategy fulfill their parental responsibilities by consciously using the parental mediation strategy. Therefore, it is essential to find out what the parents who use active co-play mediation strategy think about STEM-oriented digital games. In this context, it is believed that the opinions to be obtained from the study group in which the parents who use the active co-play strategy will contribute significantly to the literature. Another of the study's questions will be addressed by explaining the mediation strategies used by parents for digital games.

### *21.2.3 Parental Mediation*

The term *"parental mediation"* is used to describe the guidance given by parents to benefit from the positive aspects of online technology while minimizing the risks as a result of the increasing use of technology by early childhood children using touch-screen devices (Kirwil, 2009, p. 405). Parental mediation consists of parents restricting, monitoring, supervising, or guiding their children's use of technology (Warren, 2001, p. 212). The mediation strategies used by parents in different countries differ due to differences in media tools and cultural influences (Livingstone et al., 2017). In parallel with differences in the use of media tools, different parental mediation strategies have been observed for television (Valkenburg et al., 1999, p. 53), the Net (Eastin et al., 2006, p. 486), and digital games (Nikken & Jansz, 2014). The study implemented by Gözüm and Kandır (2020) reported that Turkish parents use viewing mediation, technical mediation, restrictive mediation, and "active co-playing mediation" strategies for digital games and that some parents adopt the laissez-faire mediation strategy of not using the parental approach at all. That same study reported that parents use the active co-playing strategy to allow their children to play educational games with conscious guidance. The "active co-playing mediation" strategy is the combination of active co-mediation and co-playing mediation. *"active co-playing mediation"* is when children play digital games together with their parents and discuss the game's contents with them (Livingstone et al., 2015, p. 4; Nikken & Jansz, 2014). Parents who prefer digital apps with educational content and who consciously use parental guidance use the "active co-playing mediation" strategy (Gözüm & Kandır, 2021). Vygotsky (1978) states that by transforming digital games into a scaffolding tool, parents can support their children's development areas and ensure they develop lasting learning and problem-solving skills. Parents who use the "active co-playing mediation" strategy can support their children's proximal zone by playing digital games with them and helping them with game-level levels that they cannot solve or pass. Vygotsky (1978) stated that the language used by parents with children when building this scaffolding is critical. In the "active co-playing mediation" strategy, the parent can talk about the digital game played by the children, both mastering the game's content and transforming it into a scaffolded structure that will support the child's development. The study's second question is: "*How do parents apply the "active co-playing mediation strategy when playing STEM-content digital games together with their children"?*

It is thought that this study will contribute to the literature by showing to what extent the educational content of digital games with STEM content is educational and how parents who use the "active co-playing mediation" strategy apply this strategy.

## 21.3 Method

The study was conducted using the primary qualitative research method appropriate to qualitative research (Merriam, 2009). This study focused on two situations. The first situation is parents using the "active co-playing mediation" strategy on their children who play digital games. The second situation is parents stating that children's digital games have STEM content. In this respect, this study is a qualitative study made to investigate "how parents use" the "active co-playing mediation" strategy and examine the "STEM education content" of the digital games that children play. To this end, criteria were determined for the study's working group participants. Interview and document analysis, which are qualitative research techniques, were used to collect the data for the study. Various data collection techniques such as observing, interview and document analysis can be used together in qualitative research method (Yıldırım & Şimşek, 2011). An interview form for parental guidance consisting of open-ended questions developed by Gözüm and Kandır (2021) was used. Digital games with STEM content played by children are examined as documents in the research. Digital games were downloaded online by the researcher, and document analysis was performed. The data collected in the study were transcribed, and descriptive and content analysis techniques were used. The findings obtained as a result of content and descriptive analysis in the research were combined and interpreted. The research design is explained in Fig. 21.1.

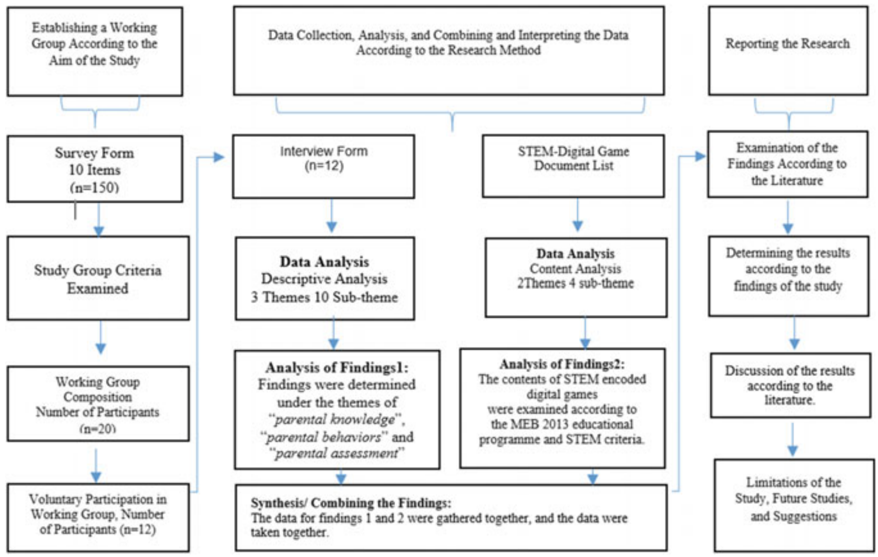


**Fig. 21.1** Research design

### 21.3.1 Working Group

The study's working group consists of 12 children aged 60–72 months at an officially independent kindergarten in Turkey's Southeast Anatolia Region and parents. The study's working group was formed using criterion sampling, a type of purposeful sampling. The criterion sought was that children play STEM-content digital games and that their parents play these games with them. When forming the study's working group, the *"Parental guidance when children play digital games questionnaire"* was administered to 200 parents via e-mail. This questionnaire was developed by Gözüm and Kandır (2021) and consisted of 11 questions. Given the aim and scope of the study, the question about aggression was removed, resulting in the parents being asked ten questions. Parents can answer yes/partially/no to the questions in the questionnaire. Parents using the "active co-playing mediation" strategy were identified by looking at the yes answer given to all the questions in this questionnaire. The *"personal information form"* administered to the parents via e-mail asked about the content of STEM encoded digital games that children play. The names of the digital games with STEM encoded that children play were detected by the answers to the questions in this form.

No limitations or conditions were imposed on the digital games mentioned by the parents who took part in the study in terms of price (paid or free), operating system (iOS or Android), the device on which they were installed, or the game's language.

A total of 20 parents were found that matched the research criteria according to the results of both the *"Parental guidance when children play digital games questionnaire"* and the administered *"personal information form."* This number fell to 12 due to the consent form that the parents had to complete to participate in the study voluntarily.

Table 21.1 gives the demographic information of the parents and children who participate in the study.

Table 21.1 shows that five of the parents participating in the study are female, and seven are male. The parents' ages in the working group ranged from 26 to 46 years. The parents have various professions such as worker, civil servant, teacher, engineer, doctor, or academic. Their education levels range from high school through undergraduate and master's degrees to Ph.D. Six of the children are girls, and seven are boys. The children play digital games on smartphones, tablets, and laptops.

### 21.3.2 Data Collection Tool

We used two data collection tools in the study. The first data collection tool was a personal information form containing the children's personal information. The second data collection tool is the unstructured interview form that consists of open-ended questions seeking the parents' opinions on parental guidance ("*Parental guidance when children play digital games questionnaire").*

**Table 21.1** Demographic characteristics of participants

| ID | Parent's | | | | Children's | | |
|---|---|---|---|---|---|---|---|
| | Gender | Age | Profession | Education level | Gender | Age | Digital tool |
| P1 | Female | 34 | Civil Servant | Bachelor's Degree | Girl | 6 | Smartphone |
| P2 | Male | 46 | Doctor | Ph.D. | Boy | 5 | Tablet |
| P3 | Female | 29 | Teacher | Bachelor's Degree | Boy | 6 | Tablet |
| P4 | Male | 26 | Engineer | Bachelor's Degree | Girl | 6 | Tablet |
| P5 | Female | 37 | Academic | Master's | Boy | 6 | Tablet |
| P6 | Female | 26 | Teacher | Bachelor's Degree | Girl | 5 | Smartphone |
| P7 | Male | 27 | Worker | Bachelor's Degree | Boy | 5 | Smartphone |
| P8 | Male | 33 | Civil Servant | Bachelor's Degree | Boy | 6 | Tablet |
| P9 | Male | 32 | Academic | Ph.D. | Girl | 6 | Laptop |
| P10 | Male | 31 | Engineer | Bachelor's Degree | Girl | 6 | Tablet |
| P11 | Male | 30 | Teacher | Master's | Boy | 5 | Tablet |
| P12 | Female | 35 | Doctor | Ph.D. | Girl | 5 | Laptop |

*"Personal Information Form"*: The researcher prepared this form to collect the personal information about the children and parents voluntarily participating in the study and the names of the digital games that children play. The aim of the study, consent to participate in it, and what STEM means were all explained in the personal information form. The parents completed the information form via Google Form. The personal information form includes two parts. The first part contains questions about the parent's personal information ("*parent's gender,*" "*age,*" "*education level,*" "*occupation,*" "*whether or not they play digital games with their child*"). The second part contains questions about the child's personal information (*"the child's gender," "age," "digital device for playing digital games, "names of digital games that were played"*).

*"Parental guidance when children play digital games questionnaire":* Gözüm and Kandır (2021) developed the questionnaire and used it to add detail to the survey form. Using it in the study is to obtain detailed information about the active co-playing strategy. The questions in the questionnaire are included in the findings with the S1 code. The question about aggression, which was removed from the survey form, was also not used in the questionnaire.

### *21.3.3 Data Collection*

We collected the study's data in three stages. The first stage of the study's data collection process is administering the personal information form and "*Parental guidance when children play digital games questionnaire.*" The second stage is administering the *"Parental guidance when children play digital games questionnaire." The third* *stage includes document analysis to collect the digital games with STEM content played by children.*

***First stage***: The personal information form and the *"Parental guidance when children play digital games questionnaire"* were completed on Google Form to create the study's working group. A Google form was e-mailed to the parents. The researcher e-mail 150 parents, of which 20 matched the criteria for inclusion in the working group. However, 8 of these parents were excluded from the study's working group because they stated they would not continue.

***Second stage***: *The "Parental guidance when children play digital games questionnaire"* was administered to collect the parents' opinions. While administering this questionnaire, the day and time of the synchronized online meeting with the parents were determined. Parents would be available to participate in the study was determined via e-mail. The day and time of the online one-on-one session were determined for each participant. The researcher informed participants that the online sessions would be recorded. The participants were told that the recorded videos would not be used for research purposes and would not be shown to third parties. The participants answered the parents' questions in the interview form in detail during the interview. The participants answered the questions, which were asked by the researcher precisely as written in the questionnaire, and no direction was given.

***Third stage***: *The researcher created a document list of the digital games that the children play. Each of them on this document list was downloaded from technology stores and played by the researcher in turn, and transcripts were made.*

### *21.3.4 Data Analysis*

Descriptive analysis was performed on the records of the data obtained from the parents who had synchronized online one-on-one interviews. A thematic framework was created for the analysis, and the data were analyzed according to this thematic framework. The findings obtained from the analyzed data are defined, then the interpretation of the findings begins (Yıldırım & Şimşek, 2011). In this study, the thematic framework created by Gözüm and Kandır (2021) was used to code the parents' views, after which the findings for the "active co-playing mediation" strategy were defined and interpreted. When conducting the descriptive analysis of the active-co play strategy, parental views were included by adding verbatim quotes to the "*parental knowledge*,*" "parental behaviors*," and "*parental assessment*" thematic framework. The parents' comments were codified and interpreted. For example, the fourth participant replied to the question "What is the purpose of the digital games your child plays?" in Table 21.2, saying, "For STEM education, for example, learning to code—P4." Two codes were derived from the parents' answers, namely, "STEM" and "coding" for the children's purpose in playing the game. The obtained codes were interpreted in light of the literature.

Content analysis was applied to the digital games with STEM content collected by document analysis, and codes and themes were created. Content analysis is the

**Table 21.2** Content analysis of games and *"parental knowledge"* on purposes of STEM encoded digital games

| |
|---|
| S.1.1. "What is the purpose of the digital games your child plays?"<br>"Developing skills for STEM—P1"; "To establish a foundation for STEM education. -P3"; "For STEM education, for example, learning to code—P4"; "… it uses the laws of physics but plays like a game within the game—P6"; "To create a foundation for coding in the future by coding the directions in the game—P9"; "… learning the foundations of the mathematical knowledge necessary for engineering and design—P21." |
| S.1.2. "How did you find out the purpose of the digital games your child is playing?"<br>"I researched the game myself and found that STEM-oriented games would be beneficial for my child—P2"; "It was a game I played; young children normally play it, but being about engineering, it caught my attention—P5"; "When my son had trouble passing a level, he would ask me questions—P7"; "…we talk about the game because it attracts my attention and my child's—P11." |
| The content of the digital game encoded with STEM content<br>When we made the content analysis of digital games, we coded the games' purposes as "STEM, coding, mathematical operations (counting, matching, comparison, ordering, classification), science (balance, matching, comparison, ordering, causality), engineering (design, part-whole relationship, matching, problem." |

careful, detailed, and systematic examination and interpretation of content to determine themes, biases, and significances concerning the aim of the study. The purpose of the content analysis in this study is to reveal the concepts and relationships that can explain the STEM content of the data obtained through document analysis (Guba & Lincoln, 1994; Maxwell, 1992). When coding the content of digital games with STEM content in the study, Aronin and Floyd's (2013) principles to be considered when parents choose a mobile app with STEM content for preschool children were taken into account. Furthermore, we took the educational outcomes of the "*Turkish Ministry of National Education's [MEB] Preschool Education Program* (2013)" as the criteria for the educational support of digital games with STEM content. In the MEB 2013 preschool education program, attempts are made to make the children achieve the educational outcomes and indicators in different development areas through various activities (MEB, 2013). According to Erol and İvrendi (2021), the MEB 2013 preschool education program can be used to plan, implement, and assess STEM-related activities for children. In the study conducted by Gözüm and Kandır (2021), the MEB 2013 outcomes and indicators were used to examine the educational aspects of the digital apps applied to children. As a result, the codes to be made based on the educational outcomes and indicators of the MEB 2013 Preschool Education Program provide data to show how educational digital games with STEM content are. In addition, the STEM sub-themes related to the digital game theme were correlated and examined under the literature review subheading, Mobile Application for STEM. Accordingly, content analysis was conducted on 28 digital games that the parents indicated. The data, the descriptive and content analyses, were combined and interpreted for the aim of the study. Figure 21.2 shows the themes and sub-themes determined due to the qualitative data analysis.

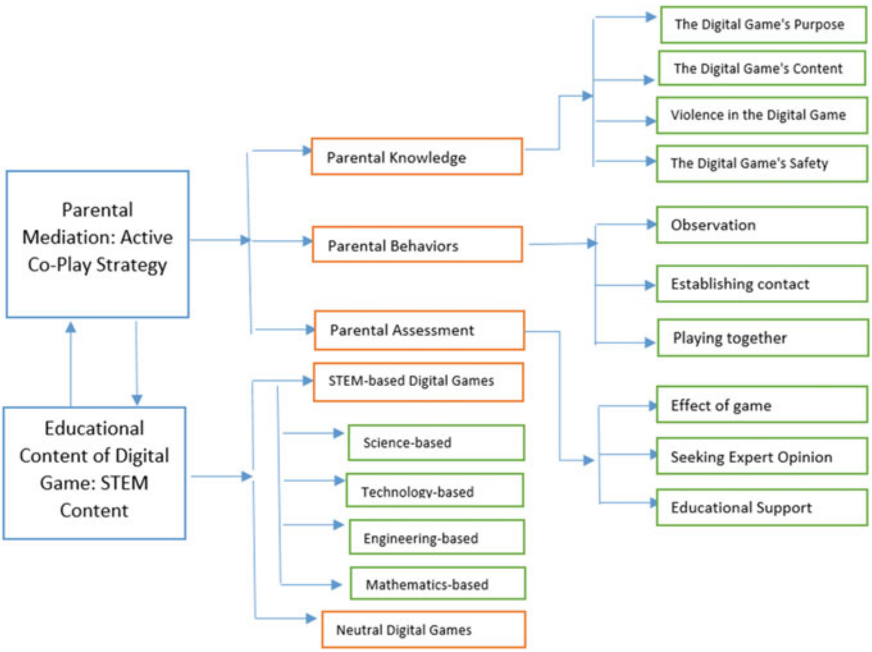


**Fig. 21.2** Themes and sub-themes formed as a result of data analysis (Orange frames are the theme and green frames are the sub-theme.)

In Fig. 21.2, it is shown that the active co-play mediation strategy includes three themes in line with the views of the parents. The thematic framework discovered by Gözüm and Kandır (2021) consists of "parental knowledge," "parental behavior," and "parental assessment," respectively. Four sub-themes were described under parental knowledge, four under parental behaviors, and three under parental assessment. Relevant codes were assigned according to 11 sub-themes, and exact quotations were included in the findings section. Figure 21.2 shows that two themes were found for digital games due to the content analysis of STEM encoded digital games. The first of these themes is STEM-based digital games; the second is *"neutral digital games."* There are four sub-themes for STEM-based digital games. Gözüm and Kandır (2021) define neutral games as games that do not have educational content and do not contain violence. Accordingly, games that do not have STEM content and do not contain violence are grouped under the neutral theme.

### *21.3.5 Qualitative Data Analysis Reliability*

The themes that emerged as a result of descriptive and content analysis were assessed using the expert review method, which is a method used in qualitative research to ensure validity and reliability (Yıldırım & Şimşek, 2011, p. 268). The themes that emerged from this analysis were examined by four faculty members working in preschool education, four faculty members researching digital games, and two faculty members studying STEM. After the examination, content analysis reliability was calculated using Miles and Huberman's (2016, p. 64) agreement percentage. The formula shows that *"Reliability = Agreement opinion/(Agreement opinion + Disagreement opinion) × 100,"* all themes which is the opinion of parents were found to be 100% in agreement. When the agreement percentage of the sub-themes for the content of STEM-based digital games is examined, it is found to be 100%, while for *"neutral games,"* it is found to be 95%.

### *21.3.6 Findings*

This study sought parents' opinions on what they knew about the STEM-content digital games played by their children, their behaviors, and their assessments. Their opinions provided the findings to the research questions "*How do parents apply the "active co-playing mediation" strategy when playing STEM-content digital games together with their children?"* Results are also given for the research question: *"Do the digital games contain STEM education?"*.

**Theme 1. *"What parents know"* about the STEM-content digital games children play.**

We gave the findings for the theme *"What parents know"* about the STEM-content digital games played by children under "sub-themes." The sub-theme "*The STEM Purpose of the Digital Game Played by Children*" is seen in Table 21.2, the sub-theme "*The Content of the Digital Game*" is seen in Table 21.3 the sub-theme "*Violent Content in the Digital Game*" is seen in Table 21.4. The sub-theme "*Safety of the Digital Game*" is seen in Table 21.5.'

### *21.3.7 The Digital Game's Purpose*

According to Table 21.2, the parents participating in the study explained the purposes of their children's games using the concepts *"STEM," "physics," "engineering," "coding," and "mathematics."* It was determined that when parents were finding out the purpose of the digital game that their children play, *"they did their research for STEM education," "their children played the games they do," and "they talked about the game."* According to the content analysis of the purposes of the digital games the children played, it was stated that they play STEM-content or STEM-related games.

**Table 21.3** Parental knowledge on the content of STEM encoded digital games

| |
|---|
| S.2.1. "What is the content of the digital game your child is playing?"<br>"The robot is actually going to the planet; however, to get the battery it needs right now, coding needs to be done…—P1"; "it is played with vans, but the vans' parts are put together, then a house is made using the stone and wood needed for the design (engineering)—P2"; "The child learns coding by listing instructions such as the number of steps left or right when he wants to make a character move—P4"; "… as a design, he creates a model by bringing children side by side, then that model is adapted to the design, the model made is tested for design suitability, these are physics-related…—P8"; "…a game that is up to the creativity of the child; they can design whatever they want but what they want to design depends on their imagination; essentially, it's not like it's science-related but it does have STEM content—P10"; "… he can make a bridge by combining the balls; he needs to calculate how many he needs to combine; then, when he reaches the objective, he goes through a pipe, but the important thing here is to calculate because if not, he might not be able to remove the obstacle…—P12." |
| S.2.2. "How did you find out the content of the digital game your child is playing?"<br>"playing together—P2"; "I know because my child played with me—P6"; "He plays the games I choose, I have already played the game—P7"; "I have researched the content of the game before, but when we are playing together, I ask if it is interesting—P8"; "Some games are not in Turkish, they can be in English; I demonstrate the game first so that the child can understand the game…—P6"; "There are not many games with Turkish content, so I show it to my child; some games do not need much language, he finds it hard until he understands—P12" |
| The content of the Digital game encoded with STEM content<br>When we analyze digital games' content, parents' opinions reflect game content. Games may be categorized as STEM, science, coding (technology), engineering, and mathematics. In this categorization, "mathematics" content was associated with almost every category |

**Table 21.4** Parental knowledge on violence in STEM encoded digital games

| |
|---|
| S.3.1. "How do you know if the digital game your child is playing contains violence or not?"<br>"I know that there are violent games, but I research games, and I care about educational content—P1"; "I bought games with STEM content to support their education using technology, particularly those without violence—P5"; "It could not be violent; we play games together, I do not think there is any game I do not know about…—P4", "…I read the comments for playing STEM content games; the other parents were also satisfied; I think the child enjoys violent games more, but if you can find a good game…—P10." |
| S.3.2. "What would you do if you found out that the digital game your child is playing contains violence?"<br>"If he is playing violent games, it means I have not checked the game. If he is going to play, I make him play a good game instead of the one he is playing—P7"; "He can play violent games, it attracts children's attention, but there are more interesting games to play. The main problem is finding those games… to do this, you have to talk, to get to know the child's interests…—P5"; "Firstly, I forbid him to play violent games, then I find a game that benefits my child instead of that game…—P4." |
| The content of the Digital game encoded with STEM content<br>When we made the content analysis of digital games, no "games containing violence" were found |

**Table 21.5** Parental knowledge about the safety of STEM encoded digital games environment

| |
|---|
| S.4.1. "How do you know if the digital games your child is playing are safe?"<br>"When we choose games for STEM with educational content, I read the reviews of the games, I want them to play the games that I believe to be safe…—P1"; "I check the PEGI classification, but the best thing to do is play games together to check whether the game is safe—P4"; "There are stars that show games' popularity ratings, so they are safe; if they have educational content, these stars are important for the quality of the game, I think that a game that is educational is safe…—P6"; "You can understand whether the games are safe or educational or not by playing the content—P10." |
| S.4.2. "What would you do if you realized it was not safe?"<br>"If the game is not safe, if it is harmful to the child, I prevent him from playing the game…—P8"; "After analyzing the events in the game well, I restrict him from playing that game—P8"; "I intervene immediately and prevent him from playing that game—P9." |
| The content of the Digital game encoded with STEM content<br>When we made the content analysis of digital games, we stated that the games contained different STEM and STEM-related contents; however, they were considered safe because they did not "advertise games of chance" or "redirecting to a different game" or have "sexual" content |

### *21.3.8 The Digital Game's Content*

According to Table 21.3, the parents participating in the study explained the purposes of their children's games using the concepts *"STEM," "physics," "engineering," "coding," and "mathematics."* It can be said that parents find out about the content of the digital games their children play by *"playing them together with their children and by communicating"* without leaving anything to chance, just as with the purpose of the game. It was also stated that the digital games did not have Turkish language settings. So the parents explained the game to their children by translating for them. It matches the contents and purposes of the digital games that children play. In games with STEM content, mathematics content was found to be associated with all fields—*"science," "engineering," and "coding"* (technology). However, only two games integrated these fields with STEM philosophy.

### *21.3.9 Violence in the Digital Game*

According to Table 21.4, it was determined that the parents who participated in the study researched the digital games that their children play before playing them to see whether or not they contained violence and preferred games with educational content. In addition, one of the reasons why parents deliberately choose games with STEM content is. Hence, their children use technology and avoid violent content while playing educational games. In this context, it was stated by the parents that their children do not play violent games. Indeed, when the contents of the digital games that children play were examined, it was stated that there were not any violent games, just STEM or STEM-related games. However, the parents said that if their children play violent digital games, they can direct them to a beneficial game in line with their children's interests and development. Parents stated that they would first restrict their children's access to these games for violent games and then find beneficial games.

### *21.3.10 Safe Digital Gaming*

According to Table 21.5, the parents participating in the study stated that they reviewed the comments about the game before playing the game to determine whether the digital games that their children played were safe and preferred educational games. It was stated that they monitored educational and secure games for their children using the star rating given to games, and they also checked them out by playing them. However, it was stated that parents would intervene and prevent their children from playing games that could be harmful or unsafe.

**Theme 2. Playing Digital Games with STEM Content: *"Parental Behaviors"***

We give the findings for *"Parental behaviors"* when playing the digital games with STEM content played by their children under sub-themes. The sub-theme "*Observing Children*" is given in Table 21.6, the sub-theme "*Detection of Communication*" is shown in Table 21.7, the sub-theme "*Playing Together*" is given in Table 21.8.

**Table 21.6** The behavior of parents who observe their children and content by STEM encoded digital games

| |
|---|
| S.5.1. "What is your reason for observing your child while playing digital games?"<br>"When my child is playing, there is a time we set for him to play, even if he plays with me, I do not want him to go beyond that period, so I observe…—P11"; "There are times in the game where he asks me, and I observe because I want to give him an answer right then—P12"; "When the child interacts with the game, he may not realize how long he has been playing, then I warn him, but since we usually play together, I observe him for our goal of reaching a certain level per day—P6"; "I particularly want to observe to see what my child will ask when they play STEM or different educational games because I want to know are the questions educational or not, or is the game suitable for the child's level or not? All these come from observing, if the child quits a digital game, it is because they are bored, but they never get bored in STEM games—P10." |
| S.5.2. "What is the content of the digital game your child is playing?"<br>"Sometimes the games whose reviews I read might not turn out to be educational, but STEM games are well designed, I think they work well together with the content…—P11"; "The content and educational content should enable them to learn technology, this is my goal, so the child should learn to code, I see this—P4"; "In fact, the child can design a house, but he should select stone and wood suitable for engineering, if the child selects these and designs the house, he will achieve his goal in the game—P2." |
| The content of the Digital game encoded with STEM content<br>When we make the content analysis of digital games, it is understood that there are games with STEM content concerning the content of the games that parents observed |

**Table 21.7** Parental behavior and content analysis of the game for communication through the digital game

| |
|---|
| S.6.1. "Have you checked whether your child is communicating with others in the digital game he is playing?"<br>"When I read the reviews for the game, I learned that the game was a single-player game. In STEM games, the child usually tries to solve a problem, there is no communication…—P2"; "When I say communication, I mean there is no commercial or occasional video in paid games, but there were videos or advertisements in a game he played, and that was for food; I do not think it was harmful—P3"; "There is no remote access or group chat games, so communication is not established. Even if it were to be established, I would see it when playing with my child—P1." |
| S.6.2. "What do you do when you realize that your child is being contacted in a digital game?"<br>"I check what he is being contacted for, but I do not find it appropriate to communicate with the child from the outside for the game, I would likely not want him to play that game—P9"; "When contact is made through a game, if it is to direct the game or from a remote center, it can be dangerous, so I forbid him to play that game—P10"; "Communicating also means guiding, and in this case, I do not want my child to be guided as a tool for the game—P11." |
| The content of the Digital game encoded with STEM content<br>The codes related to digital games are grouped into three sections. These sections are "non-verbal communication," "one-way communication," and "two-way communication." No game was found in the "two-way communication" category in the content analysis. However, advertisements were displayed on screen in the "one-way communication" category, and photographs for advertising purposes were displayed on screen in the "non-verbal communication" category |

**Table 21.8** The behavior of parents who play STEM encoded digital games with their children

| |
|---|
| S.7.1. "What is your reason for playing the digital game with your child?"<br>"I want my child to benefit positively from technology, and I particularly want him to play educational games. These games include STEM games, but when children get stuck in STEM games, you have to help them. Otherwise, the game will not progress, and the child will lose interest—P4"; "I want my child to play digital games for his education…, as, for the content, STEM is critical, many areas are involved at the same time, and the child can learn without realizing it. … I like these games too…—P5." |
| S.7.2. "What is the content of the digital game you play with your child?"<br>"Ostensibly, it only makes one robot progress, but that robot's progress depends on your coding, so the child learns basic coding for STEM—P4"; "Children can make a bridge with simple rods in science for inventions or a hanger to carry a load, but will the bridge or the hanger carry that load? While testing it, the game you are also playing attempts the scenario you make. If it is correct, the bridge will stand, but if it is wrong, it will collapse…—P7"; "The child needs to create a structure while placing the puzzle pieces; there is an element of balance in this structure, but for me, calculating the remaining distance in the structure is true engineering…—P9"; "When the child transfers the heterogeneous colors mixed in the glass bottles to the empty bottles and obtains homogeneous mixtures, he realizes which bottle to empty in which order; the important thing is to make the child think in this way—P12.“ |
| The content of the Digital game encoded with STEM content<br>When we analyze digital games' content, parents' opinions reflect game content. The games ensure progress while creating a structure, doing a puzzle, or solving a problem as part of their content, STEM—science, coding (technology), engineering, or mathematics |

### 21.3.11 Observing Children

According to Table 21.6, it was stated that the reasons why the parents participating in the study observed the digital games their children played were the time they played and helped their children achieve the goal of the game. Parents emphasized that the games played with STEM content were well designed, achieving the STEM goal. Content analyses of digital games coincide with parent observations, and it can be said that the games they told their children play have STEM educational value.

### 21.3.12 Detection of Communication

According to Table 21.7, when the parents' views in the study regarding communication in digital games that their children play are examined, they stated that there is no communication in the paid STEM games. Still, contact is made in the free STEM games for advertising purposes. Parents do not want the game in question to be played, thinking that communication with their children will be directed through the game. When the content of digital games was examined, parental views and content analysis of the game were similar. While there was no communication in paid games, *"non-verbal communication" and "one-way communication"* were detected in free games.

### 21.3.13 Playing Games Together

According to Table 21.8, the parents participating in the study play the digital games played by their children together. The reason for which parents play digital games with their children can be explained as supporting children's progress in STEM content games and parents keeping their children interested. Parents know that they are playing STEM games with their children, and they see the game's content right down to the last detail. Indeed, digital game content analysis and parent views support each other.

**Theme 3. Digital Games' Effects with STEM Content: *"Parental Assessment"***

We give the findings for the effects of digital games with STEM content played by children under the sub-themes of the *"Parental Assessment"* theme. We offer sub-theme "*Effects of Digital Games*" in Table 21.9, "*Seeking Expert Opinion*" in Table 21.10, and a sub-theme of the educational support provided by digital games in Table 21.11.

**Table 21.9** Parents' assessment of the effects of STEM encoded digital games children play

| |
|---|
| S.8.1. "What are the effects of the digital games your child plays?"<br>"When the child does coding, this shows what task he will do in which order and what outcome it will produce… the most important effect is its reflection on daily life because what a child essentially needs to do in life is a plan and organize, I see the effects of coding on this—P4"; "It may seem like it has no effect at first glance, but it is very effective, it affects counting; when the glass is too close to the edge of the table, to predict that the glass might fall if the table is shaken is an important effect—P5"; "It affects the child because when I am arranging my bookshelf at home, I can see it affects his thinking when he says that book will not fit on the shelf because the shelf is too small and he describes laying the books flat like in the game—P12." |
| S.8.2. "What do you do to eliminate the effects that you consider negative?"<br>"The child is not aware of what he is playing, sometimes I am not aware of what might develop by playing, but I want him to play good games to remove the negative effects; the problem is that most of the games are not in Turkish…—P6"; "Here, if you leave the child alone, they will be negatively affected, but I researched STEM games well, I think they are very beneficial, so the child needs to play games randomly for there to be any negativity…—P9"; "To avoid being negatively affected, children should be assisted until they gain experience, just as with everything else, the child cannot stop himself from playing and if he is not aware of the negative effects, I should intervene, the same as anything else…—P10." |
| The content of the Digital game encoded with STEM content<br>The digital games mentioned by parents have been divided into two categories based on their effect on children. Categories specified by parents: "positive affect" and "neutral." |

**Table 21.10** Parental assessment of seeking expert opinion on STEM encoded digital games their children play

| |
|---|
| S.9.1. "What is your reason for seeking an expert opinion about the digital games your child plays?"<br>"We are in a world where there are so many digital games and apps, games may be paid, they may be educational, but I search on sites where expert opinions are posted because games are complex things…—P1"; "I find out about games that support children's education by asking experts, but there are difficulties about this issue, experts recommend very few games; a computer programmer who is an expert in STEM games gave me recommendations…—P5"; "My brother teaches computing, he played that digital game to his children before me. His comments are critical to me because he also played the games and the games he suggested were useful for education, so you have to listen to people who know…—P12." |
| The content of the Digital game encoded with STEM content<br>The opinion of parents who sought expert opinion is examined. They recommended games with STEM content or science, coding (technology), engineering, mathematics, language, or art |

### *21.3.14 Effects of Digital Games*

According to Table 21.9, according to the parents participating in the study, it is argued that digital games with STEM content positively support cognitive developments such as planning and organizing, estimating, establishing relationships, cause-effect, and reasoning. Since their children have low awareness, parents blame themselves for the adverse effects of digital games on children. It is emphasized that their games should not be left to chance for children not to be negatively affected.

**Table 21.11** Parents' assessment of the educational support of STEM encoded digital games played by children

| |
|---|
| S. 10.1 "What is the content of the digital game that you think contributed to their education?" "Children's coding skills can be improved with digital games…—P4"; "For science and engineering, children need to use many skills, mathematics is the foundation and STEM can develop all of them…—P6"; "Skills that are important for children to develop in STEM… when solving a problem or placing a Lego brick, the important thing is to solve the problem faced, and to do this they have to count, match, and think …—P7." |
| S. 10.2 "What do you do to make your child play digital games that you think to support their education?" "Digital games already attract the child's attention and interest immediately, but you have to make him understand the game by playing with him; sometimes he may not want to play games with educational content, then you have to play together and show the game's processes…—P8"; "The child can play games by asking questions about the points they are curious about, but if he enjoys the game, he already plays on his own. You have to help him in the game's stages that he cannot pass. Children should be playing educational games without realizing that they are playing educational games. Still, if these games are didactic, they will get bored, he builds bridges in STEM games, but he learns so much…—P6"; "When I want to play an educational game for children, I first talk about its interesting aspects, for example, how we can make the robot walk; if we make the robot walk, we will eventually go to its planet; we can see this in practice when the child is playing the robot; in fact, he can learn the basics of coding…—P4." |
| The content of the Digital game encoded with STEM content The digital games preferred by the parents were examined according to their educational gains, and it was broken down into five sub-themes. These themes are: "STEM," "science-based digital games," "technology-coding-based digital games," "engineering-based digital games," and "mathematics-based digital games." |

When the content analysis of STEM coded digital games is examined, it has been determined that although there are 24 games in the positive impact category, four games contain fixed and didactic instructions designed to pass the time rather than create a positive or negative impact. Based on this, it can be said that parents choose positive STEM games for their children.

### *21.3.15 Seeking Expert Opinion*

According to Table 21.10, the parents who participated in the study sought expert opinions about the games their children play because they could not predict the effects of the complex content of the digital games and support their children's learning. On examination of the contents of the games for which expert opinion was sought, it is understood that they are related to STEM and its sub-fields. It was determined that expert opinion was sought for the content of 24 out of the 28 digital games examined and not aimed for the remaining four games.

### *21.3.16 Digital Games' Support for Education*

According to Table 21.11, the parents stated that their children's mathematics skills improved in developing their coding skills and science and engineering skills. Their mental skills, such as problem-solving, also improved. Parents stressed that for children to play educational digital games, they have to ask questions that pique their interest, explain that part of the game that will attract their attention, and assist them in the levels where they are struggling. The digital games the parents said their children were played as "STEM," "science-based digital games," "technology-based digital games," "engineering-based digital games," and "mathematics-based digital games." In this regard, parents let their children play STEM-coded digital games that contribute to their learning. As a result of content analysis based on STEM content and educational gains, the digital games were listed under the "educational content of digital games."

## 21.4 Digital Games' Educational Content

According to the parent reports, digital games were coded by the researcher according to STEM content by playing the games and paired with the educational gains. The STEM-related sub-themes of digital games consist of STEM components. According to the reports given by the parents, the total number of STEM-coded digital games played by children is 28. While 24 of the digital games were STEM content, four games were determined neutral.

### *21.4.1 The First Theme is STEM-Based Digital Games*

According to Aronin and Floyd (2013), the principles to be considered when choosing a tablet or computer app to provide STEM experience for preschool children are: The source of action should be the child, the child should be able to initiate the action. Children should be able to establish the cause-and-effect relationship within the digital game. Changes in the outcomes of situations in which children intervene should be observable. Children's effects in the game should be visible quickly to achieve the result and reinforce the cause-effect relationship. Parents' views in their selection of digital games were examined following the principles proposed by Aronin and Floyd (2013).

According to parents' opinions coded P2, P5, P7, and P11 (see Table 21.2), Table 21.2), the principal action is asking questions when the children play digital games. Furthermore, children can initiate the action by playing the parents' digital game (see Table 21.2, P2). However, parents P4, P6, and P8 emphasized the need to '*explain the game*,' '*ask questions*, or '*show gameplay'* that would arouse curiosity should the children be unwilling to play educational games with STEM content (see Table 21.11). According to the views of parents P6, P10, and P12, children continue in the game without getting bored, go through the game stages at different levels, and ask questions about the game content (see Table 21.6). In the light of parental opinions, it can be thought that children know the change in a situation when parents interfere during their progress in digital games, realize the consequences, and form a cause-and-effect relationship. In the light of the findings obtained, the principles to be considered known the selection of digital games according to Aronin and Floyd (2013) were found to be realized to the parents' views.

The digital games with STEM content played by children were examined according to the 2013 MEB preschool education program educational outcomes and indicators and the definitions of quality STEM application under the Mobile Applications for STEM subheading. Digital games with STEM content can combine STEM content and an area that includes science, technology, engineering, and math skills. It was determined that the science, technology, engineering, and mathematics skills of STEM are used together in building and construction games.

A bridge, a tower, sometimes a robot can be designed. Alternatively, it may be coding to solve a problem. In the games examined in this context, children make their designs to make a safe bridge. After the bridge is built, its durability is tested. When the skills acquired by the children are examined, it is clear that the games support their *"classification," "ordering," "guessing," "part-whole," "matching," "counting," "comparing,"* "*establishing cause and effect relationship,"* and "*problem-solving"* skills. When these skills are examined, content is seen that can support the skills of "*counting," "classification,"* and *"ordering"* for the number of parts needed to make a safe bridge, and the *"part-whole" and "matching"* skills for the suitability of the elements. Children can test the durability of the bridge after building it. During this test process, children can guess whether what they are doing is durable or not. If it is durable, it is understood that the children are solving problems. The educational outcomes in the game aimed at building bridges played by children match the content of 2013 MEB preschool education program educational outcomes and indicators ("*classification*," "*ordering*," "*guessing*," "*part-whole*," "*matching*," "*counting*," "*comparing*," "*establishing a cause-and-effect relationship*," and "problem-solving") (MEB, 2013). When the literature on digital games with STEM content is examined, according to Lange et al. (2019), children in early childhood can make designs using various materials. Children's self-made designs support their skills such as counting, matching, and part-whole relationships (Lange et al., 2019; Texley & Ruud, 2018). Apart from this example, since they mainly use the STEM sub-themes of science, technology, engineering, or mathematics, or a combination of these disciplines, it was found that the games are STEM-supported games. Below, the sub-themes of STEM-supported digital games are explained one by one under sub-theme headings since they stand out in specific areas. The reason for explaining sub-themes is to better explain the educational aspect of game content. However, it should be noted that the sub-themes are closely related to each other due to the nature of each STEM.

### 21.4.2 Sub-theme 1: Science-Based Digital Games

In the examination of the sub-themes, the content of the games will be explained first. The STEM content will be defined by establishing a relationship with the MEB 2013 Preschool Education Program. In this context, according to the parents' reports, when the STEM-coded digital games played by the children are examined, there is a game based on connecting gear wheels. Chains and pulleys are used to move the wheels in the game. This game was studied under science-based digital games. The game's content matches the "*classification*," "*ordering*," "*guessing*," "*part-whole*," "*matching*," "*counting*," "*comparing*," "*establishing a cause-effect relationship*," and "*problem-solving"* educational outcomes of MEB 2013. In another digital game, children play with a fish that left the aquarium back to the aquarium. Children who want to take this fish back to the aquarium can use pipes, wheels, spray, and blocks. The game's content matches such MEB 2013 educational outcomes as "*trial and error*," "*grouping*," "*comparing*," "*sequencing*," "*space-position-related planning*," and "*measuring objects.* "Children use square boxes to help a robot overcome the obstacles it runs into when getting it out of an enclosed area. The game's content matches such MEB 2013 educational outcomes as "*space-position-related planning*," "*measuring objects*," "*forming patterns*," "*comparing*," and "*ordering*."

It is observed that physics comes to the fore in the science-based digital games played by children. According to content analysis, STEM-based digital games come with science and engineering content together by combining science topics such as *"Gravity," "balance," "force," and "momentum"* with engineering design. In this sub-theme, children's skills such as *"grouping,"* "*comparing," "ordering," "space-position planning," "measuring objects," "pattern forming," "block design," "building design," "landscaping," "drawing," "trial and error,"* and *"expressing themselves in creative ways"* are coded as among the gains provided by these games. When the child wants to design a tower that he does not want to collapse under gravity, he may discover that the parts that fall due to gravity are out of balance, and the factors that do not fall are in harmony. Although this application example seems science-based, there is direct interaction with engineering due to the nature of its STEM content (Bredekamp, 2015; MacDonald, 2015; Moomaw, 2013).

### 21.4.3 Sub-theme 2: Technology/Coding-Based Digital Games

According to the reports of the parents, when the STEM coded digital games played by the children are examined, it is seen that children use ground-direction (right, left, forward, stop) commands so a robot, animal, or monster can follow the instruction given or reach the objective. This digital game was studied under technology-coding-based digital games. The content of the game is to move the robot or animal using commands; the outcomes of "*space-position-based planning*," "*sequencing*" commands in a specific order to reach the objective, "*counting*" at a basic level when calculating the route to be taken by the robot or animal, "*trial and error*" in getting the coded created to move, and solution suggestions for the problems encountered" matched the MEB 2013 educational outcomes.

In the technology-based digital games played by children, robot construction is observed as the interaction between engineering and design in STEM. In this sub-theme, skills such as *"question–answer," "directing the character," "learning symbolic digital code concepts,"* "*improving the implementation of the instructions given at the particular location," "trial and error,"* and *"improving suggested solutions for the problems encountered"* were coded among the games' gains. In addition, it was determined that the games that motivate players to solve a technology-based problem use coding to activate the main character. For example, the child who is asked to code the path that a robot must follow to get its battery should direct the character to answer the question as to how to obtain the battery; the symbolic codes for controlling the character should be put in order, and the implementation of the instructions given at the location according to these codes should be developed. Solutions will be developed for the problems encountered should the robot reach the battery. Although this application example seems technology-based, it supports coding, essential in STEM content. According to Bers (2010), children getting the robot to move is the basis for programming. Children can acquire coding and ground-direction learning outcomes by making the robot move.

### *21.4.4 Sub-theme 3: Engineering-Based Digital Games*

According to the parents' reports, when the STEM-coded digital games played by the children are examined, a house can be left without a roof, and the child can be asked to design different roofs for it. Games were found where the child can make designs by choosing among various shapes such as square, triangle, and circle or combining shapes when designing the roof. This game was studied under science-based digital games. The content of the game matches such MEB 2013 educational outcomes as "*comparison*," "*sequencing*," "*part-whole*," "*matching*," "*trial and error*," "*counting*," "*space-position-related planning*," "*measuring objects*," "*forming patterns*," "*establishing cause-and-effect relationships*," and "*problem-solving*." Another game played by children involves organizing the place and position of objects such as rows, shelves, books, and cabinets that will act as blocks so that a ball that falls from the cupboard can land in a basket. The content of this game matches the same educational outcomes as the previous game. Another game is designed to support and balance by using a certain number of iron pipe blocks to help children lift a weight or stop a tree from falling over. The game itself tests whether the design provides support and balance. In this game, unlike the other two games, it has been determined that children gain the outcome of "expressing themselves in creative ways." Children can use their creativity to form endurance and balance using a set number of iron blocks. In engineering-based digital games, children are asked to make a house, an electronic device, a truck, or a design. Allowing the child to use their imagination to complete the design is a process that develops creativity. Engineering-based digital games are directly related to both science and mathematics. According to Lange et al. (2019) 34, when children construct by modeling their creative ideas on various structures, this supports their skills toward STEM education.

In the engineering-based digital games played by children, Lego, building, and construction games are observed for the engineering use of STEM. Since children can express themselves esthetically and creatively in these games, this is a critical effect of STEM-based digital games. In this sub-theme, it is coded that such skills as *"grouping," "comparison," "sequencing," "part-whole," "matching," "counting," "space-position related planning," "measuring objects," "pattern forming," "block design," "structural design," "landscaping," "drawing," "expressing themselves creatively," "trial and error,"* and *"suggesting solutions for the problems encountered"* can be improved during the game. The skills identified in the games can be developed, according to Lange et al. (2019), and acquired, according to Tuxley and Ruud (2018), through STEM activities. Furthermore, the use of materials in various areas, shapes, and sizes that children will prefer in mobile apps provides the opportunity to support children's visual-spatial skills (MacDonald et al., 2015).

### *21.4.5 Sub-theme 4: Mathematics-Based Digital Games*

According to the parents' reports, when the STEM-coded digital games played by the children are examined, as a discipline, mathematics can be used in all the content of technology-, engineering and science-based digital games. However, although the analyzed games look like they are for children to practice engineering design, it was determined that they are essentially aimed at acquiring mathematical skills. For example, when a math-based digital game is examined because it is coded as an engineering-based game but has a lot of math content, a house's roof is left off, and children choose the triangle shape. The house door was left off, and the children were asked to place the rectangular shape where the door should go. The aim of the game is math-based as it focuses on acquiring concepts for geometric shapes. This game's content matched the "*comparison*," "*part-whole*," and "*matching*" educational outcomes of the 2013 MEB Preschool Education Program. In a different game example, when children make steps or a path according to the balance principle, which has science content, in a puzzle by using a set number of cubes, educational outcomes such as "*counting*" and "*forming patterns*" can be acquired with 5 or 6 objects. In the content of another digital game, the educational outcomes of "*measuring objects*," "*guessing*," and "*matching*" are used to move water from full containers to empty containers without spilling any into containers or pipes.

In mathematics-based digital games, children play, numbers, patterns, and operations are the expected uses of STEM mathematics. In these games, children start with basic skills such as counting, adding, subtracting numbers, forming part-whole, and pattern-making. Here, children lay the foundations of processes such as advanced probability. In this sub-theme, it is coded that such skills as *“grouping,”* “*comparison,” “ordering,” “part-whole,” “matching,” “counting,” “measuring objects,” and “pattern forming”* can be improved during the game. For example, with an object, not only will a structure be built, but also a sufficient number of things to reach the objective will be made. A meaningful pattern is expected to be formed when performing this operation. When the codes are examined in light of the literature, it was determined that according to Moomaw (2013), it is appropriate for children to gain basic mathematical skills such as number and operation, measurement, part-whole, and comparison using apps with STEM content. In this example, the children perform operations using objects, create a structure, and make an engineering-oriented design. Mathematics is used in both technology and science games. According to Bredekamp (2015), children can gain basic math skills and skills in other areas of STEM in STEM-related activities.

## 21.5 Conclusion and Discussion

In this part of the study, the conclusions reached in light of the findings are discussed within the scope of the literature. The study’s conclusion and discussion follow two tracks. The first track examines how parents use the “active co-playing mediation” strategy on their children who play digital games. The second track concerns the content of the digital games children play in terms of STEM and educational value. Based on this, to understand how parents use the “active co-playing mediation” strategy, the results obtained from the “parental knowledge,” “parental behaviors,” and “parental assessment” sub-themes and discussion are included.

It has been determined that children’s academic skills are positively supported when parents engage in activities that support children’s education in early childhood (Patrikakou, 1997; Reynolds & Clements, 2005). The involvement of parents in their children’s activities has led to an increase in children’s cognitive skills and a decrease in their problematic behaviors at school (Melhuish et al., 2001). During the early childhood years, young children spend most of their time at home and school, so the role of parents in support of their children’s education is critical (Simpkins et al., 2005). Bus et al. (1995) determined that language and social cohesion are high due to the support given by parents to their children’s education. Berkowitz et al. (2015) showed that math skills are high, while Fleer and Rillero (1999) indicated that science skills improve. According to Mullis et al. (2004), the positive effect of parents on the education of children in the early years is lasting. Today, the COVID-19 global pandemic has forced children to spend more time at home. When children spend time at home, it is even more important that parents support their children. Since their children use mobile apps at home, parents want to use them to meet their children’s educational needs. In this context, parents use the study’s subject of digital games with STEM content and the “active co-playing mediation” strategies in the process of their children who play these games will be discussed under the themes “*parental knowledge*,” “*parental behaviors*,” and “*parental assessment*.”

Under the *"parental knowledge"* theme, it was stated that the parents whose children play digital games with STEM content know the purpose of the digital game, its content, whether or not it contains violence, and that the game is safe for their child (see Tables 21.2, 21.3, 21.4 and 21.5). The study by Gentile (2003) reported that one-third of parents know the digital games played by their children. It was determined that the parents participating in this study see the name and the purpose and content of the game because they play it with their children. According to Gözüm and Kandır (2021), knowing the scope and purpose of the digital games the children play indicates that they deliberately use parental guidance. Another situation known as laissez-faire mediation, which is not actual mediation, may occur when the parent does not knowingly provide advice. However, there was no evidence of laissez-faire mediation among the parents participating in the study. The content analysis of the games the children of the parents play and the views of the parents was found to be consistent. In this regard, it can be said that parents deliberately use the "active co-playing mediation" strategy. However, examining the findings of all themes as a whole will show us how the "active co-playing mediation" strategy is used. Based on this, the *"parental behaviors"* theme results are explained below.

When *"parental behaviors"* are examined in the process of playing digital games with STEM content, it can be seen that the reason parents use *"observation"* is to answer questions that the child may ask about the game, to monitor the child's digital game playing time, to track the game's progress daily, and to determine the appropriateness of the digital game for the child's development and age (see Table 21.6). In light of these findings, when parents check and monitor digital games to see if they are appropriate to their child's developmental level when choosing digital games for their child, this is known as "*viewing mediation*" (Hasebrink et al., 2011; Livingstone & Helsper, 2008; Livingstone et al., 2015; Valkenburg et al., 1999). It is thus understood that parents use the "*viewing mediation"* strategy when monitoring their children by transforming it into the *"active co-playing mediation"* strategy.

When parents' views on *"establishing communication"* via the digital game are examined, it is seen that even though communication is not established in educational games such as STEM, one-way or verbal communication such as advertising is established in free games. Since parents do not find it appropriate for digital games to communicate with their children, they do not want their children to play games that establish communication (see Table 21.7). Livingstone et al. (2015) say that *Restrictive mediation* is a situation where digital play is restricted when parents notice the harmful effects of the digital games children play. It is, therefore, understood that parents can use the restrictive mediation strategy for their children. Parents are aware that they are keeping children away from online risks while playing digital games, and they emphasized that there is no risk in games with STEM content. It is concluded that parents can keep their children away from online threats when using the active co-playing strategy (Livingstone & Helsper, 2008; Nikken & Jansz, 2014). Mesch (2009) states that the risk of children being exposed to cyberbullying decreases due to parents using the "active co-playing mediation" strategy. Piotrowski (2017) says that active and restrictive mediation can be used in early childhood.

When the reasons for the parental behavior of *"playing together"* are examined, they are seen to be to assist the child in play games the parent thinks have educational benefits for their child, to go up levels in the digital game with educational value, to support the child's latent learning in digital games with educational value such as STEM, and to stop the child losing interest in the educational digital game played by the child when they cannot progress (see Table 21.8). Vygotsky's (1986) theory on learning through socio-cultural interaction emphasized that children's learning can be supported by knowledgeable adults. According to Vygotsky (1978), an experienced adult can support a child's learning helping him/her gain knowledge and experience. Today, parents can use digital games as scaffolding to support children's learning in this context. The child can learn something by himself, but he may need to be supported by an adult in the face of problems he cannot solve. This helps the child's learning. From this point of view, parental support facilitates the child's teaching in cases where children cannot progress in digital games with STEM content. Considering Vygotsky's (1986) theory on social interaction and the fact that social interaction is formed between the child and the parent via the game, it can be said that this is the setting in which active co-playing is observed. Gözüm and Kandır (2021) reported that parents who positively support the development of their children aged 60–72 months use the *"active co-playing mediation"* strategy. Parents should use digital apps with STEM content for their children to benefit more from digital apps with STEM content. According to Vygotsky (1978), the adult language is critical in the scaffolding to be established between the adult and the child. For a parent to talk to a child about a digital game, it should be the most natural thing to know about the game's content.

Vygotsky's (1986) theory emphasizes that children may need adult guidance in solving the problems they face. This means the child's development will be supported by solving the problems he encounters with adult assistance. In the study, the views of parent P4 in the verbatim quotes uphold the need for parental support for STEM content (see Table 21.8, P4). I wonder how a parent who has not played the digital game with STEM content being played by their child can help when the child asks about a problem he is stuck on in the game. If the parent wants to help, they are expected to explore that game by playing it. If he does not want to help, this may indicate negligent mediation. This situation will introduce many online risks and the child's risk of not playing educational games with STEM content. The parents who participated in the study deliberately used the *"active co-playing mediation"* strategy to promote their children's positive development and prevent online risks. The assessments of parents who use the *"active co-playing mediation"* concerning the effects of digital games are explained below.

When *"parental assessment"* of the effects of digital games with STEM content is examined, they expressed the following views about *"the effects of digital games"*: Examples are given of how they affect children's cause-effect relationships, counting, guessing, and reasoning skills (see Table 21.9). In their thoughts on the adverse effects of children on digital games, the parents emphasize that the reason digital games are harmful does not have good content or not being well-chosen by the parent and that parents need to take responsibility (see Table 21.9). In early childhood, children cannot be expected to choose positive digital games for themselves. Indeed, the parents are responsible for selecting digital games that positively affect (Schofield Clark, 2011). However, it is difficult for parents to choose these digital games. According to Papadakis and Kalogiannakis (2020), determining whether the content of digital games is educational or not is not an easy and controversial issue even for experts, but what the games are missing or lacking can be determined. Parents can use the *"active co-playing mediation"* strategy to determine what is missing or lacking. However, even if they use this strategy, they must choose digital games for their children by seeking expert advice. The views of parents on getting specialist opinions on digital games in this regard are explained.

When the parents' views on *"seeking expert opinion"* for digital games with STEM content are examined, they stated that due to the complex aspects of digital games, they research experts' opinions, get ideas from experts for digital games with educational content, and seek the views of experts who are also relatives who have tried out the digital games children play (see Table 21.10). In their study, Gözüm and Kandır (2021) stated that the digital games played by children whose parents sought expert opinion and applied the *"active co-playing mediation"* strategy had educational value.

When parents' opinions on the *"educational support"* aspect of digital games are examined, the parents think that they need to have STEM content to support their child's education. Parents state that digital games with STEM content support coding, science, mathematics, and engineering (see Table 21.11). Parents stated that for their children to play games with educational content, they need to explain the game's processes by playing the games with their children and ask them questions about the game and said that the children's games needed to have non-didactic content and be able children's attention (see Table 21.11). The study conducted by Yelland et al. said (2017) reported that the educational apps developed for STEM have very little educational value. At the end of the study by Papadakis and Kalogiannakis (2017), parents and educators were given information about the educational value of mobile apps prepared for children. This information emphasized that mobile apps have more entertainment content than educational value. This being so, it is even more important that parents use the *"active co-playing mediation"* strategy to determine educational content. Acting on this, although the parents who participated in the study said that STEM content games have a positive impact on their children, the emphasis on the need for parents to play digital games with their children and explain the games' processes shows that parents have a critical role to play when it comes to the content of digital games. Indeed, parents' emphasized games attracted children's attention instead of didactic games. Parents do not consider didactic games educational using the "active co-playing mediation" strategy. Flewitt et al. (2015) emphasized in their study that most of the mobile apps that claim to be educational consist of didactic worksheets or puzzles. At this point, let us return to the second track of the study, namely, the examination of the content of the digital games children play in terms of STEM and educational value.

It has been stated that most applications that are developed for children in early childhood have low educational value and aim to entertain children (Papadakis et al., 2016a). However, technology can be used positively to support children's development. In their experimental study, Papadakis et al. (2016b) determined that mobile apps designed to improve children's mathematics proficiency can also be used to support their educational skills. Indeed, according to Yelland et al. (2017), STEM education in early childhood lets children fashion their curiosity about the world holistically. STEM education provides learning environments where children's thinking skills and scientific knowledge processes are actively used. Kalogiannakis and Papadakis (2020) emphasized the importance of developing mobile apps for STEM activities in preschool classrooms. According to the study results, improving the STEM skills of children studying in a STEM learning environment can increase their interest in STEM and their educational gains, making it important for career choices and academic achievement in later life. Therefore, there is a need to develop quality mobile apps for STEM. In this respect, it is good for their children that the parents participating in the study prefer digital games with STEM content. Even though children need to play games with STEM content in the literature, the educational design of mobile apps is under debate. On examination of the findings for the second track of the study *("Do the digital games children play enhance STEM education?")*, the digital games children play are grouped under the themes of STEM-based, science-based, technology/coding-based, mathematics-based, and engineering-based. The study found that the total number of digital games children play is 28. While 24 of the digital games were found to be STEM content, four games were determined neutral. It was determined that children's digital games, when expert advice was sought, have STEM content, and those games chosen without expert advice have no educational value. However, the children participating in the study play at least one STEM content game with educational value. According to Aronin and Floyd (2013), experts' opinions are effective in digital games analyzed according to the principles to be considered when choosing a tablet or computer app to provide preschool children with experience in STEM. The study by Papadakis and Kalogiannakis (2020) concluded that most mobile apps have entertainment content, not educational content. It is not easy for parents to choose digital games with educational content for their children. The four neutral games without educational content identified in this study were chosen by parents without seeking expert opinion, similar to the study results by Papadakis and Kalogiannakis (2020). Another finding of the study on digital games with STEM content is that parents translate foreign language games to their children due to the limited language choice of digital games played by children. Therefore, it is also apparent that the game developers with STEM content need to increase the options for different languages. In this regard, what parents should pay attention to when choosing digital games with STEM content needs to be discussed. Parents' assessment of the quality of digital games with STEM content requires much expertise and research. This discussion is moot because it is unrealistic to expect expertise from parents on many issues. According to the study results, parents' seeking expert opinion has a particularly acute effect. It has been determined that the content of the games based on expert opinion is of good quality. However, another important criterion when choosing games with STEM content is parents' interest in games. This is because parents research the games before their children play them. Parents are also aware of their children's interest in games and their requirements, so they predict at what stage of the game their child would get bored and quit. In this case, when we look at Aronin and Floyd's (2013) views of parents in terms of their principles in choosing digital games, it can be argued that parents reflect their experiences in digital games onto their children, and not by coincidence. Another important factor that was found when parents choose digital games for their children is the relationship between parents' professions and STEM. The finding that best reveals this relationship is the quotes taken from parent P4 and parent P10, who are both engineers (see Tables 21.2, 21.3, 21.4, and 21.5), showing that the games played by the parents and those played by their children have engineering content. In addition, parents also emphasize that their children's games should be selected according to the PEGI classification. The study results show that among the games with STEM content, parents focus on STEM content without focusing on digital games that are STEM brands. This is because the names of the games do not include the word STEM. Furthermore, it has been determined that parents focus on choosing a STEM app in line with their children's interests rather than a specific STEM discipline.

In light of the discussions above, the study reached the following conclusion: When parents deliberately use the *"active co-playing mediation"* strategy, they could choose appropriate digital games with STEM content for their children. Moving on from this, the critical question of the study, namely, "*how do parents use*" the *"active co-playing mediation"* strategy? It is summarized below after a discussion of the literature.

When the parental knowledge, behaviors, and assessment themes are evaluated as a whole, it is understood how parents use the active co-playing strategy. First of all, parents know that digital games are beneficial for their children. Children should play well-structured digital games to benefit from digital games educationally. Since parents play digital games with their children, they are aware of the game's content and how it affects their daily lives. It is understood that parents seek expert opinions on educationally beneficial digital games, do research, and seek the views of experienced friends and relatives. The reason why those parents who use the active co-playing strategy observe their children is to assist their children in the digital game in which they progress educationally. Parents who use the active co-playing strategy help their children progress in the digital game. When using the "*active co-playing mediation*" strategy, the parents block digital games that negatively affect their children and direct them to games that will positively affect them. They make an educated assessment of the content of digital games. Parents can chat with the child about aspects of the game's content that arouses curiosity and ask questions to pique the child's interest in STEM encoded digital games with educational content. It is thus understood that parents apply the "*restrictive*" and "*viewing mediation*" strategies in addition to the "*active co-playing mediation*" strategy to their children in the early childhood years.

### Recommendations

Experts should organize parent training to choose digital games matching their children's interests and needs. The educational content of digital games selected by parents who seek expert opinion can significantly contribute to children. Furthermore, game developers need to improve the different language options in digital games with STEM content. As for the mediation strategy parents should apply to their children, if a case in this study is to be an example, parents should be trained in how to use *"active co-playing mediation"* strategies. Of course, projects for longitudinal research into this education can be planned considering the parents' working conditions, education levels, and technology literacy levels.

### Limitations and Future Research

The parents participating in this study had undergraduate, master's, and Ph.D. levels of education. The lack of participants with lower education levels is an essential limitation of the study. However, the analysis can be applied to a broader range of participants by diversifying the education levels of those parents using the *"active co-playing mediation"* strategy. The results of this study are difficult to generalize due to the nature of qualitative research. However, the study has yielded significant findings regarding how the *"active co-playing mediation"* strategy is used and the content of digital games with STEM content. For future research, the results of this study can be compared with the results of studies made in different countries with different cultures and participants.

## References

Aladé, F., Lauricella, A. R., Beaudoin-Ryan, L., & Wartella, E. (2016). Measuring with Murray: Touchscreen technology and preschoolers' STEM learning. *Computers in Human Behavior, 62*, 433–441.

Aronin, S., & Floyd, K. K. (2013). Using an iPad in inclusive preschool classrooms to introduce STEM concepts. *Teaching Exceptional Children, 45*(4), 34–39.

Berkowitz, T., Schaeffer, M. W., Maloney, E. A., Peterson, L., Gregor, C., Levine, S. C., & Beilock, S. L. (2015). Math at home adds up to achievement in school. *Science, 350*(6257), 196–198.

Bers, M. U. (2010). The TangibleK robotics program: Applied computational thinking for young children. *Early Childhood Research & Practice, 12*(2), 1–20. Retrieved from http://ecrp.uiuc.edu/v12n2/bers.html

Bilton, H., & Watts, M. (2019). Early stem education: Practice and prospects. *Early Child Development and Care*. https://doi.org/10.1080/03004430.2019.1653547

Bredekamp, S. (2015). *Erken çocukluk eğitiminde etkili uygulamalar* (T. İnan ve H. Z. İnan, çev.). Nobel Akademi Yayıncılık.

Bus, A., van Ijzendoorn, M., & Pellegrini, A. (1995). Joint book reading makes for success in learning to read: A meta-analysis on intergenerational transmission of literacy. *Review of Educational Research, 65*, 1–21.

Charette, R. N. (2014). STEM sense and nonsense. *Educational Leadership, 72*(4), 79–83.

Clements, D., & Sarama, J. (2016). Math, science, and technology in the early grades. *The Future of Children, 26*(2), 75–95.

Early STEM Matters. (2017). Early STEM matters: Providing high-quality STEM experiences for all young learners. A policy report by early STEM matters. Early Childhood STEM Working Group. http://ecstem.uchicago.edu

Eastin, M. S., Greenberg, B. S., & Hofschire, L. (2006). Parenting the internet. *Journal of Communication, 56*(3), 486–504. https://doi.org/10.1111/j.1460-2466.2006.00297.x

Erol, A., & İvrendi, A. (2021). Erken çocuklukta STEM eğitimi. *Erken Çocukluk Çalışmaları Dergisi, 5*(1), 255–284.

Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A Professional development approach centered on an engineering design challenge. *International Journal of STEM Education, 4*(1), 6.

Fleer, M., & Rillero, P. (1999). Family involvement in science education: What are the outcomes for parents and students? *Studies in Science Education, 34*(1), 93–114.

Flewitt, R., Messer, D., & Kucirkova, N. (2015). New directions for early literacy in a digital age: The iPad. *Journal of Early Childhood Literacy, 15*(3), 289–310.

Gartel, D. (2016). Developmentally appropriate STEM: It's STREAM! https://drjuliejg.files.wordpress.com/2015/03/developmentally-appropriate-stem-stream.pdf adresinden alınmıştır

Gentile, D. A. (Ed.). (2003). *Advances in applied developmental psychology. A complete guide for parents and professionals.* Praeger Publishers/Greenwood Publishing Group.

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford University Press.

Gonzalez, H. B., & Kuenzi, J. J. (2012, August). Science, technology, engineering, and mathematics (STEM) education: (CRS Report No. R42642). Retrieved April 14, 2020, from Congressional Research Service website. https://fas.org/sgp/crs/misc/R42642.pdf

Gözüm, A. İC., & Kandır, A. (2020). Developing a parental mediation scale of digital games for children. *International Journal of Curriculum and Instruction, 12*(2), 336–358.

Gözüm, A. İC., & Kandır, A. (2021). Digital games pre-schoolers play: Parental mediation and examination of educational content. *Education and Information Technologies, 26*(3), 3293–3326.

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Ed.). *Handbook of Qualitative Research* (pp. 105–117). SAGE Publications, Inc.

Hasebrink, U., Görzig, A., Haddon, L., Kalmus, V., & Livingstone, S. (2011). *Patterns of risk and safety online: In-depth analyses from the EU kids online survey of 9- to 16-year-olds and their parents in 25 European countries.* London School of Economics and Political Science.

Kalogiannakis, M., & Papadakis, S. (2020). The use of developmentally mobile applications for preparing pre-service teachers to promote STEM activities in preschool classrooms. In *Mobile Learning Applications in Early Childhood Education* (pp. 82–100). IGI Global.

Kirwil, L. (2009). Parental mediation of children's internet use in different European countries. *Journal of Children and Media, 3*(4), 394–409. https://doi.org/10.1080/17482790903233440

Lange, A., Brenneman, K., & Mano, H. (2019). *Teaching STEM in the preschool classroom exploring big ideas with 3- to 5-year-olds.* Teachers College Press.

Livingstone, S., & Helsper, E. J. (2008). Parental mediation of children's internet use. *Journal of Broadcasting & Electronic Media, 52*(4), 581–599. https://doi.org/10.1080/08838150802437396

Livingstone, S., Mascheroni, G., Dreier, M., Chaudron, S., & Lagae, K. (2015). *How parents of young children manage digital devices at home: The role of income, education and parental style.* EU Kids Online, LSE.

Livingstone, S., Ólafsson, K., Helsper, E. J., Lupiáñez-Villanueva, F., Veltri, G. A., & Folkvord, F. (2017). Maximizing opportunities and minimizing risks for children online: The role of digital skills in emerging strategies of parental mediation. *Journal of Communication, 67*(1), 82–105. https://doi.org/10.1111/jcom.12277

Looi, C. K., Zhang, B., Chen, W., Seow, P., Chia, G., Norris, C., & Soloway, E. (2011). 1:1 mobile inquiry learning experience for primary science students: A study of learning effectiveness. *Journal of Computer Assisted Learning, 27*(3), 269–287. https://doi.org/10.1111/j.1365-2729.2010.00390.x

MacDonald, A. (2015). Technological tools, ICTS and digital play. İn A. MacDonald & J. Rafferty (Ed). *Investigating mathematics, science and technology in early childhood* (pp. 52–77.). Oxford University Press.

MacDonald, A. S., Wendell, K., Douglass, A., Love, M. L. (2015). Engaging young engineers teaching problem-solving skills through STEM. Paul H. Brookes Publishing Co.

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(2). https://doi.org/10.1186/s40594-018-0151-2

Maxwell, J. (1992). Understanding and validity in qualitative research. *Harvard Educational Review, 62*(3), 279–301.

Melhuish, E., Quinn, L., Sylva, K., Sammons, P., Siraj-Blatchford, I., Taggart, B., McSherry, K., & McCrory, M. (2001). *Cognitive and social/behavioural development at 3–4 years in relation to family background*. The Stranmillis Press. The Joan Ganz Cooney Center at Sesame Workshop.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. Jossey-Bass.

Mesch, G. S. (2009). Parental mediation, online activities, and cyberbullying. *Cyberpsychology & behavior, 12*(4), 387–393.

Miles, M. B., & Huberman, A. M. (2016). *Genişletilmiş bir kaynak kitap: Nitel veri analizi*. In S. AkbabaAltun & A. Ersoy, Çev. (Eds.). Pegem Akademi.

Milli Eğitim Bakanlığı [MEB]. (2013). Okul öncesi eğitim programı. Ankara: MEB.

Moomaw, S. (2013). *Teaching STEM in the early years: Activities for integrating science, technology, engineering, and mathematics*. Redleaf Press.

Mullis, R. L., Mullis, A. K., Comille, T. A., Ritchson, A. D., & Sullender, M. S. (2004). *Early literacy outcomes and parental involvement*. FL, Florida State University.

Mundie, J., & Hooper, S. (2014). Considering the potential of connected mobile learning. In C. Miller & A. Doering (Eds.), *The new landscape of mobile learning* (pp. 8–18). Routledge.

Nikken, P., & Jansz, J. (2014). Developing scales to measure parental mediation of young children's internet use. *Learning, Media and Technology, 39*(2), 250–266. https://doi.org/10.1080/17439884.2013.782038

Papadakis, S. (2018a). Gender stereotypes in Greek computer science school textbooks. *International Journal of Teaching and Case Studies, 9*(1), 48–71. https://doi.org/10.1504/IJTCS.2018.090196

Papadakis, S. (2018b). The use of computer games in classroom environment. *International Journal of Teaching and Case Studies, 9*(1), 1–25. https://doi.org/10.1504/IJTCS.2018.090191

Papadakis, S., & Kalogiannakis, M. (2017). Mobile educational applications for children. What educators and parents need to know. *International Journal of Mobile Learning and Organisation (Special Issue on Mobile Learning Applications and Strategies), 11*(3), 256–277.

Papadakis, S., & Kalogiannakis, M. (2020). A research synthesis of the educational value of self-proclaimed Mobile educational applications for young age children. In S. Papadakis & M. Kalogiannakis (Eds.), *Mobile learning applications in early childhood education* (pp. 1–19). IGI Global. https://doi.org/10.4018/978-1-7998-1486-3.ch001

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016a). Developing fundamental programming concepts and computational thinking with ScratchJr in preschool education: A case study. *International Journal of Mobile Learning and Organisation, 10*(3), 187–202.

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016b). Comparing tablets and PCs in teaching mathematics: An attempt to improve mathematics competence in early childhood education. *Preschool and Primary Education, 4*(2), 241–253.

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2017a). Designing and creating an educational app rubric for preschool teachers. *Education and Information Technologies, 22*(6), 3147–3165. https://doi.org/10.1007/s10639-017-9579-0

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2017b). Improving mathematics teaching in kindergarten with realistic mathematical education. *Early Childhood Education Journal, 45*(3), 369–378. https://doi.org/10.1007/s10643-015-0768-4

Patrikakou, E. N. (1997). A model of parental attitudes and the academic achievement of adolescents. *Journal of Research & Development in Education, 31*(1), 7–26.

Piotrowski, J. T. (2017). The parental media mediation context of young children's media use. In R. Barr & D. N. Linebarger (Eds.), *Media exposure during infancy and early childhood: The effects of content and context on learning and development* (pp. 205–219). Springer. https://doi.org/10.1007/978-3-319-45102-2_13

Reynolds, A. J., & Clements, M. A. (2005). Parent involvement and children's school success. In E. Patrikakou, & R. P. Weissberg (Eds.), *Family-school partnerships.* Teachers College Press.

Rushkoff, D. (2010). *Program or be programmed: Ten commands for a digital age.* O/R Books.

Sarama, J., Clements, D., Nielsen, N., Blanton, M., Romance, N., Hoover, M., … McCulloch, C., (2018). Considerations for STEM education from PreK through grade 3. Education Development Center, Inc. http://cadrek12.org/resources/considerationsstem-education-prek-through-grade-3 adresinden alınmıştır

Schofield Clark, L. (2011). Parental mediation theory for the digital age. *Communication Theory, 21*(4), 323–343.

Sharifnia, E., Vidiksis, R., Orr, J., Dominguez, X., Goldstein, M., & Kamdar, D. (2015). Developing preschool scientists: Identifying best practices for using tablets to support early science teaching and learning. İn *Society for Information Technology & Teacher Education International Conference* (pp. 1745–1750). ABD.

Sherry, J. L. (2015). Formative research for STEM educational games. *Zeitschrift Für Psychologie, 221*(2), 90–97.

Simpkins, S. D., Davis-Kean, P. E., & Eccles, J. S. (2005). Parents' socializing behavior and children's participation in math, science, and computer out-of-school activities. *Applied Developmental Science, 9*(1), 14–30.

Sung, Y.-T., Chang, K.-E., & Liu, T.-C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers & Education, 94*(252), 275.

Texley, J., & Ruud, R. M. (2018). Teaching STEM literacy: A constructivist approach for ages 3–8. Redleaf Press.

Valkenburg, P. M., Krcmar, M., Peeters, A. L., & Marseille, N. M. (1999). Developing a scale to assess three styles of television mediation: "Instructive mediation", "restrictive mediation", and "social coviewing." *Journal of Broadcasting & Electronic Media, 43*, 52–66. https://doi.org/10.1080/08838159909364474

Vygotsky, L. S. (1978). *Mind in society*. Harvard University Press.

Vygotsky, L. S. (1986). *Thought and language.* MIT Press.

Warren, R. (2001). In words and deeds: Parental involvement and mediation of children's television viewing. *The Journal of Family Communication, 1*(211), 231. https://doi.org/10.1207/S15327698JFC0104_01

Yelland, N., & Gilbert, C. (2018). Transformative technologies and play in the early years: Using tablets for new learning. *Global Studies of Childhood, 8*(2), 152–161. https://doi.org/10.1177/2043610617734985

Yelland, N., Drake, P., & Sadler, K. (2017). Early Learning in stem: Multimodal learning in the 21st century. Project Report. Victoria University, Melbourne. Retrieved on October 10, 2020, from https://docs.education.gov.au/documents/early-learning-stem-multimodal-learning-21st-century

Yıldırım, A., & Şimsek, H. (2011). *Sosyal bilimlerde nitel arastirma yöntemleri* (8th ed.). Seckin Yayinevi.

Zaranis, N., Kalogiannakis, M., & Papadakis, S. (2013). Using mobile devices for teaching realistic mathematics in kindergarten education. *Creative Education, 4*, 1–10.

# Chapter 22
# Introducing Digital Technologies into Play-Based Learning in Early Childhood

**George Aranda, Coral Campbell, Joseph Ferguson, and Chris Speldewinde**

**Abstract** Young children are increasingly engaging with digital technologies in their homes and in pre-schools around Australia, however there is a lack of understanding about the type of early years pedagogy needed to support children's play and learning with digital technologies. This chapter examines research in three preschool settings in which educators introduced digital technologies to their children. In the three case studies, we are reporting on the actions, dispositions and behaviours of the children as captured by the chosen moments informed by our observations (field notes and observational templates) and teachers' comments (in response to interviews). Our research questioned how robotic devices such as Beebots could support and complement children's STEM learning. Data were analysed using a deductive thematic approach and an instructional embodiment framework that considered how physical and imaginary embodied cognition were apparent in the children's interactions and experiences with tangible coding technologies such as Beebots. We found that embodied cognition was embedded in a variety of STEM play situations and was integral to the development of children's learning. Children's pretend play aligned with imagined embodiment and was influential in a variety of play situations, enabling digital learning. We found that Beebots did afford embodied learning and the research demonstrates the potential for facilitating imaginative embodiment in the context of play-based learning. Beebots can form part of a rich teaching and learning technologies environment and must be considered as part of the physical makeup of the educational context. Digital technologies in play-based learning should be considered as part of teachers' planning and designing of the learning environment.

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## 22.1 Introduction

Young children are increasingly engaging with digital technologies in their homes and in pre-schools around Australia (Edwards, 2016). However, Fleer (2017) indicates that there is a lack of understanding about the type of early years pedagogy that is needed to support children's play and learning with digital technologies. In particular, little is known about digital pedagogical practices and children's growth in digital competencies (Edwards & Bird, 2015) such as tangible coding technologies. In this chapter, we focus on describing our research in preschool settings where educators introduced digital technologies (in the form of Beebots) to their children using direct and surrogate embodiment. Our research questioned how Beebots and robotic devices could support and complement children's learning in STEM. This enabled opportunities for the children to use these technological devices to explore a range of learning areas including mathematics, geometry, computational thinking and science, technology, engineering and mathematics (STEM) in play-based ways. We followed the educators' practices as they introduced children to digital technologies and how they continued to scaffold the learning. As we explored children's interactions with the Beebots and the educators, we considered the intersections of play, pedagogy and learning through embodiment.

## 22.2 Play-Based Learning and STEM Education

Play is recognised as the basic medium for child development. "The child moves forward essentially through play activity. Only in this sense play can be considered a leading activity, that determines child development" (Vygotsky, 1978, p. 103). However, there is an ongoing impact on early childhood education in relation to developmental theories, child-centred approaches to learning through discovery, exploration and play, and to planning the curriculum around children's needs and interests (Wood, 2007). 'Teacher-centred' and 'child-centred' approaches are frequently constructed as binaries. Many of the currently accepted early childhood schools such as Montesorri are underpinned by child-centred approaches that see children as competent and capable learners, often with teachers taking a hands-off approach to intervening in children's activities (Campbell & Speldewinde, 2020). Hedges and Cooper (2016) highlight that narrow interpretations of play-based pedagogies have dominated the long-held ideologies of child-centred approaches. Due in part to the strong ideological stance on child-centred approaches in early childhood education and care, many early childhood educators and teachers have been reluctant to intervene in children's play situations (Pyle & Danniels, 2017; Speldewinde et al., 2020). Some teachers still see play and learning as separate constructs (Pyle & Danniels, 2017) and are therefore disadvantaged when trying to meet the challenges of assessing children's learning. Other teachers believe play could support academic learning and that teachers fill an important role in play (Campbell & Speldewinde, 2020; Pyle &

Danniels, 2017). A child's knowledge construction (working theory) provides both a mechanism and a mediating link for developing everyday knowledge and scientific knowledge (Hedges, 2012). Social interactions involved in play situations can aid and enhance children's growing knowledge construction (Campbell, 2020). Children's knowledge construction often evolves during inquiry activities as they work with others to attempt to understand and explain connections between experiences, information, and understandings (Hedges, 2012). In agreement, Edwards (2017, p. 4) writes that "social interactions and observational learning also create powerful pedagogical learning environments for young children". In addition, the Practice Principle-Teaching and Learning Guide (DET, 2017, p. 8) suggests that "children lead their learning through exploring, experimenting, investigating and being creative in ways that they initiate and control". However, the Guide highlights that there is a role for adults and teachers in child-directed play "to observe what the child knows and understands based on what they make, write, draw, say and do" (p. 8).

Play-based learning is considered a cornerstone of early childhood education with "explicit attention directed towards play-based pedagogies, guiding young learners …" (Gibson & Gunn, 2020, p. 33) with the ideas of teacher scaffolding and intervention being developed through the concept of intentional teaching. Recent research seeks to illuminate and extend the role of the teaching during play. The role of the teacher is crucial to children's learning, to support children's thinking and understanding, particularly during play (Hedges & Cooper, 2016). Edwards (2017) developed the ideas of the teacher's role in play-based learning considering three types of play (open-ended, modelled and purposefully-framed) and the various points of teacher intervention. In open-ended play children are exploring new ideas themselves, often with others, but a teacher can be 'helping' or offering suggestions. In modelled-play, the teacher's role is to work with children to help illustrate something new. In purposefully-framed play, children are co-developing understandings with the teacher using a range of different resources. However, teachers' purposeful intervention in play can occur at any point across these three types of play, indicating that teachers operate across a continuum of play-based approaches.

Play-based learning is a pedagogy that allows for child-led play where children can follow their own interests, or guided-play with intentional teaching which is child-directed, but the educator can be involved as a co-player (Fleer, 2019). Children benefit from increased engagement by creating and expanding their own learning and through manipulation they learn how things in their environment work. This engagement in learning involves children in experiencing STEM in play-based situations. During their play, children will be afforded opportunities where development of knowledge or understanding are key aspects of the play experience, while at other times, learning how to apply skills will be more relevant. Interpretations of STEM in preschool are contested, however, there is a general understanding that STEM learning "could include all or some of the four elements of STEM" (Campbell, 2020, p. 186). In child-centred play, this tends to be exhibited through integrated activities, initiated by the child or children themselves. Kermani and Aldemir (2015) highlight that STEM in early childhood is preferably holistic and child-centred, while focussing on project- and problem-based tasks. Using real problems, children undertake their own inquiries and practise skills such as observing, questioning, reflecting on evidence, justifying and communicating. However, specific discipline-based concept learning in STEM areas does occur occasionally through teacher-directed or teacher-scaffolded activities (Campbell et al., 2018). In her research, Fleer (2011) highlighted how cognition and imagination develop in complexity and work together in play-based situations to support concept formation.

However, Çetin and Demircan (2020, p. 1324) highlight that "the components of STEM education do not have equal popularity and understanding in the classrooms of early childhood education". While most early childhood education teachers are familiar with the mathematical and scientific components of STEM education (Moomaw, 2013), the technology and engineering aspects gain little attention. Educational robotics materials may provide STEM educational experiences for children, familiarizing them with the logic behind computer science and engineering. Hands-on experiences with educational robots can provide children with opportunities to engage with simple logic concepts (Sullivan & Bers, 2016). Bers (2008) comments that children can make interdisciplinary explorations and personal connections through the use of robotics in education, which is considered an effective way of engaging children with STEM in developmentally appropriate ways.

It has been suggested that technological devices such as those with screens, those that respond to movement or light (e.g. Arduinos with sensors), or move (e.g. robots) can greatly enhance children's play (Fleer, 2019). For instance, tangible coding technologies (TCTs) are digital technologies that can support coding and play without the need for a screen. Coding of these technologies can be done using various mechanisms, including scannable blocks, moveable tokens or pressing buttons. The benefits of using TCTs are a greater emphasis on students being imaginative creators and not just consumers, reducing the potential for distraction offered by screens and reducing reliance on written language (Murcia et al., 2018). TCTs typically move and can perform actions in the physical world, allowing them to be easily integrated into play-based learning.

This connection with the physical world allows teachers and students to utilise embodied cognition when using TCTs, focussing on the body as a regulator (Wilson & Foglia, 2017) where cognition and the body interact with the physical world in time and space.

## 22.3 Embodied Cognition and STEM

Embodied cognition is a way to explain how we make meaning of the world in our physical interactions with that world, and the linking of mind to body, has a rich history in educational research in regard to understanding the complex processes and experiences of teaching and learning (Fugate et al., 2019). Embodied cognition is not a single theory that can be applied to all contexts in the same way (Wilson, 2002), but rather as Wellsby and Paxman (2014) point out it is "a broad term used to describe a class of theories within cognitive science" which form "a continuum ranging from strongly embodied to disembodied, differing in their assumptions about the nature of the relationship between sensorimotor and cognitive processing" (p. 1). Despite this variation, all forms of embodied cognition theory used in educational research "assume our actions and bodily experiences are crucial to our cognitive processing" and more specifically that "direct sensorimotor interactions are essential for gaining knowledge and developing cognitive capabilities…and higher order and offline cognitive processing (i.e., removed from the environment) involve re-enactment of the bodily states from previous experience" (p. 1). In this way, as Barsalou (2008) argues for grounded cognition—which is a particularly popular theory of embodied cognition but which nonetheless encapsulates many of the defining characteristics of embodied cognition as a broader theory—this approach "rejects traditional views that cognition is computation on amodal symbols in a modular system, independent of the brain's modal systems for perception, action, and introspection" (p. 617) and instead "proposes that modal simulations, bodily states, and situated action underlie cognition" (p. 617).

The rise of STEM as a means by which students in primary school, secondary school and increasingly early childhood education settings can more fully value and positively identify with the STEM disciplines (Li et al., 2020) has involved a change in the physical constitution of classrooms that has potentially important implications for the way in which teachers and students enact and experience STEM. Classrooms are increasingly populated with various STEM instruments (e.g. digital data collection tools, tangible technologies, Virtual Reality (VR)), as reflected in the rise of makerspaces (Keuene & Peppler, 2019), that not only more closely align school science with how scientists do their work (Crawford, 2015), but which potentially make for richer interactions between students' and teachers' minds and bodies and the physical and conceptual environments in which they are immersed as they do science. Those researching STEM are increasingly making use of embodied cognition to explore the affordances and challenges of this new STEM landscape (Hayes & Kraemer, 2017; Weisberg & Newcombe, 2017). This includes the early childhood play-based learning context for which much more research is required (Wellsby & Paxman, 2014) to determine how teachers can best support children through embodied means to productively engage with their surroundings. As Weisberg and Newcombe (2017) point out, STEM education is particularly suited to an embodied cognition approach because in order for students to understand the abstract nature of these disciplines then their bodies' interactions with the instruments that make up the material STEM environment need to be understood and supported in strategic ways.

Hachey et al. (2021) argue that "children's attitudes about STEM are formed early" and as such it is important to explore the way in which "the ecology of early childhood classrooms can either afford or deny access to relevant experiences that help children nurture early self-understandings and ways of positioning themselves in relation to STEM" (p. 1). In their research, Hachey et al. (2021) focused on makerspace pedagogy as a particular manifestation of STEM play-based learning in the early childhood education setting that points to the need to better understand and appreciate the way in which teachers and students do STEM in meaningful ways through their minds and bodies, which necessitates a consideration of embodied cognition. When it comes to the early childhood education context, much of this STEM teaching and learning manifests in play-based form, with Roessingh and Bence (2018) making clear through their conceptual framework for play-based pedagogy in the context of literacy education that such approaches must not only involve purposeful play and position the child at the centre of this activity, but need also to value embodied cognition. This is because "the body-mind-brain pathways and connections" (p. 31) that children need to develop in order to meaningfully engage with and learn from/about the world can only form if children have opportunities to physically interact with their material surroundings in ways that are structured to interlink with the concepts and ideas (in our case, STEM) that are the focus of play.

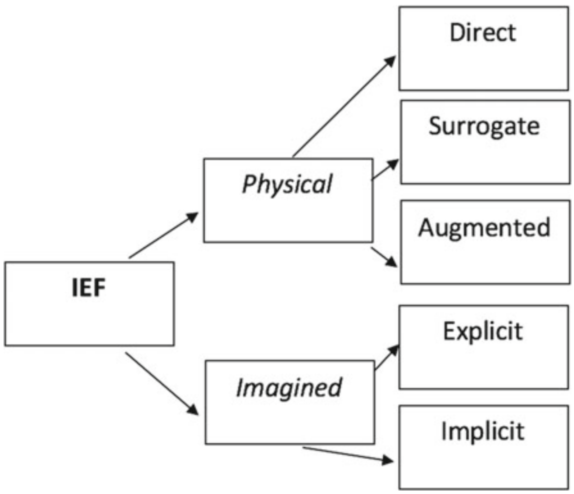
A key part of such STEM-infused early childhood education settings is increasingly the presence of tangible devices which "connect physical objects and digital worlds through tangible user interfaces" (Chan, 2020, p. 441). Newhouse et al. (2017) "investigated the ways that young children interact with discrete programmable digital toys in a free play setting" (p. 1). Children were introduced to Spheros and Beebots by their teachers and then provided with the opportunity to undertake various play-based activities that made use of these tangible devices to develop digital technology competencies. Their findings show that children require explicit scaffolding from the teacher in order to purposefully interact with such tangible devices, with such purposeful interaction in this study involving the children undertaking more desirable activities such as problem-solving. In a similar study, Baccaglini-Frank et al. (2020) demonstrate the power of embodied cognition theory to explore the value of such tangible technologies for children and their teacher. They investigated the way in which early childhood teachers related to a GeomBot, a purpose-built tangible device for mathematics, and the impact this had on student learning. Through the use of the GeomBot, they argue that this "led to new mathematical considerations for the teachers, and therefore, very likely, to different mathematical learning of their students" (p. 404) as both were comfortable in approaching this tangible device as a physical entity that was less threatening than mathematics in a more abstract form. In this way, Baccaglini-Frank et al. (2020) suggest that embodied cognition must also be 'sensuous cognition' in that the material artefacts which students and teachers interact with are multimodal in nature, in that interactions with such tangible devices involve students and teachers not only thinking and sensing but also feeling (both physically feeling objects, and emotionally feeling in response to such experiences with objects) as they do so.

In their study of primary school students' engagement with Beebots, as well as VR headsets and tablet computers, to learn about Archaic history, Ioannou and Ioannou (2020) demonstrated the power of the 'Instructional Embodiment Framework' (IEF) proposed by Black et al. (2012) to inform understanding of students' and teachers' engagement with tangible devices. The IEF has been extensively and productively applied in various education contexts over the past decade, and increasingly in STEM education (e.g. Kang et al., 2021; Mathayas et al., 2021; Reinhold et al., 2020). Instructional embodiment is "the use of action and perception for the development of understanding and comprehension or imagined embodiment within a formal instructional setting" (Black et al., p. 215). This framework (see Fig. 22.1), intended to inform the design of "learning environments that improve student learning and understanding" (p. 200) and designed for use in the classroom setting, determines two types of embodiment: *physical embodiment* (acting with one's own body) and *imagined embodiment* (embodying action and perception in *implicit* and *explicit* ways through imagination), with the former affording the latter. Physical embodiment is the focus of this research as was made possible by the data collected, with imaginative embodiment only analysed in a more speculative and general way (not at the level of *implicit* and *explicit*) as limited by the data collected.

Three distinct forms of *physical embodiment* are possible: *direct embodiment* is "when the learner physically enacts a scenario using his or her body to enact statements or sequences"; *surrogate embodiment* is "controlled by the learner whereby the manipulation of an external 'surrogate' represents the individual"; and *augmented embodiment* is "the use of a representational system, such as an avatar, in conjunction with an augmented feedback system…to embed the embodied learner within an augmented representational system" (p. 216). These distinct conceptualisations of embodiment can be used in the form of the IEF to analyse meaning making processes, including that taking place in formal education settings such as early childhood centres (Black et al., 2012). The children in the study by Ioannou and Ioannou (2020) showed "positive learning gains and attitudes" (p. 91) which were afforded by the rich and diverse mind/body experiences made possible by the different forms of embodiment enabled by the learning environment consisting of VR headsets, Beebots and tablet computers.

While early childhood teachers recognise the value of such tangible objects for student engagement and learning, they are also concerned that they lack the specific know-how and confidence to take full advantage of these technologies (Chan, 2020). As Yıldırım (2021) points out, early childhood educators do value STEM highly and

**Fig. 22.1** A schematic of the instructional motivational framework (adapted from Black et al., 2012)



attempt to enact it in their practice, but lack the content knowledge to do so with confidence and in an impactful way. Thus there is a need, as Chan (2020) makes clear, for teachers, both pre-service and in-service, to be provided with carefully scaffolded and supervised opportunities "to enact, simulate, and rehearse practice" (p. 449) with tangible technologies. As the work of Newhouse et al. (2017) and Baccaglini-Frank et al. (2020) makes clear, such research and professional development can be productively framed by theories of embodied cognition.

## 22.4 Tangible Coding Technologies—Beebots

A variety of devices exist for children to develop understandings of robotics and coding. When Flannery and Bers (2013) assessed kindergarten children's programming, they found demonstrable reasoning-based behaviors. Children would apply open-ended reasoning and trial and error with their usage of robotic devices.

For the purposes of this chapter, the focus was on a particular TCT—Beebots. Beebots are a widely popular TCT that resembles a bee. Complete with seven interface buttons (see Fig. 22.2), the user programs the Beebot with instructions to move forward, backwards and turn left or right which are temporarily stored in memory by the Beebot. The remaining buttons allow for a code being enacted (GO), to be paused, and for the Beebot's memory to be cleared. The commands to make the Beebot move can be cleared and reprogramming is a simple process (Newhouse et al., 2017). Typically they have been designed as engaging robots for young children to use when


**Fig. 22.2** The structure and controls of a Beebot

learning specifically how to code and more broadly about computational thinking concepts (Murcia et al., 2018). Children make the Beebot move by pressing a button indicating a direction and over a sequence are able to program a path that the robot can use. Beebots can be used in conjunction with mats that focus on different themes (e.g. the alphabet, coins, numbers, community buildings) and allow it to be incorporated into different challenges where the children need to program the Beebot to 'land' at different locations (e.g. "the first letter of your name" "the sum of these two numbers"). This incorporation of mats allows educators and children to use the Beebots in playful ways that consolidate ideas they are already developing. This use of mats as physical objects allows children to focus on moving the Beebot in the physical world and educators can create challenges where the children need to navigate them through different physical challenges (e.g. a maze, a mat with a flower garden drawn on it) or to incorporate familiar role play themes (e.g. navigating the Beetbot to their hive/home). In addition, Beebots have been used extensively to engage young children in STEM experiences, specifically science. In the BOTSTEM project (Final BOTSTEM 01A1 Report, 2017), one group of children investigated how Beebots could move up ramps. They were specifically studying the slope (incline) of the ramp in terms of the Beebot's movement and the point at which the Beebot failed to climb. They were experiencing the effects of the science concepts of friction and gravity on the Beebot. Children constructed their own ramps, with teacher guidance and were actively involved in altering the ramp's height above the floor to change the slope, demonstrating inquiry skills.

## 22.5 Aims of the Project

A pilot project was developed and undertaken to provide insight into the conditions of success of the application of digital technologies in early childhood. We aimed to better understand how early childhood experiences of robotics occur in the Australian context where play-based pedagogy is of paramount importance. In particular, we were interested to understand how children interacted with Beebots and used their play situations to physically engage with the small robots. We decided to provide background information to the educators in relation to unplugged programming activities to help them relate to some simple experiences for the children.

Our research design was to observe three educators and their preschool cohorts in three different settings. We conducted short interviews with the educators and spoke with the children during their play with the Beebots. Our data consists of the responses to interviews and our researcher notes written at the time of the observation. As we observed the children at play and educators at work, we became interested in how educators were introducing the concepts of coding, computational thinking and STEM using the Beebots through embodied cognition and how the children were interpreting these instructions. In this chapter, we will be discussing the observations of children's engagement with the Beebots, using the IEF (Black et al., 2012). Our intention is to demonstrate children's learning using embodied cognition.

Our research question is: How can Beebots and robotic devices support and complement children's learning?

In particular, we were investigating whether as children engage in free-play exploration, inspection and the manipulation of Beebots, they were exploring elements from the 'electronic world', things that exist around them in their everyday surroundings (Levy & Mioduser, 2010). As children may experience interdisciplinary skills and knowledge, mathematical concepts like sequencing, scientific inquiry, and problem solving (Çetin & Demircan, 2020), we were interested to observe the educators' interactions and scaffolding of learning.

## 22.6 Method

Our project design included three to four sessions at each preschool setting, depending on educator need. One session incorporated the professional learning for the educators, and two (or more) sessions were for observation and discussions (semi-structured interviews) with the educators. An Observation Protocol was developed using Milford and Tippet (2015) Classroom Observation Protocol (COP) related to children's STEM skills, and included the factors of further inputs/resources andeducators' interactions with children. Data collected included: transcriptions of semi-structured interviews with the educators who participated (Brenner, 2006), with a focus on their reflections on the teaching and learning process with the Beebots; descriptions of children while they were playing with the Beebots according to the predetermined observation protocol (COP) (Anwar & Meneske, 2021); researcher field notes that reflected the classroom observations (Phillippi & Lauderdale, 2018) as also informed by video footage and photographs of children interacting with the Beebots.

### *22.6.1 Deductive Thematic Analysis*

We undertook a deductive thematic analysis (Braun & Clarke, 2006; Nowell et al., 2017) of the data as we applied the preexisting IEF categories to code aspects of STEM learning moments in children's play as captured by the various data (in particular the field notes and educator interview responses). Thus this deductive thematic analysis consisted of two separate but related stages; (1) "purposeful selection" (Ferguson et al., 2019, p. 132) of moments as examples, followed by (2) application of the IEF. The first stage involved identifying pertinent STEM learning moments in children's play, particularly as captured in the field notes and educator interview responses, which constituted those moments that the researchers deemed likely, based on their familiarity with the data set and relevant literature, to provide insights into children's productive engagement with the Beebots. Secondly, these chosen moments were coded using the IEF (Black et al., 2012) to analyse—again working mainly with the field notes and educator interview responses—the different ways in which the educators and children undertook STEM learning through/as embodied cognition. This involved a particular focus on *physical embodiment* involving firstly *direct* and then *surrogate embodiment*, and some potential for *augmented embodimen*t. These categories of direct, surrogate and augmented enabled a characterisation of the embodied nature of children's STEM learning experiences. In the three case studies, we are reporting on the actions, dispositions and behaviours of the children as captured by the chosen moments that are informed by our observations (field notes) and educators' comments (in response to interviews).

The questions to the children were open-ended and included:

- Can you tell me what you are doing?
- What are you making the Beebot do?
- How does the Beebot work?
- What else could you do with the Beebot?

### *22.6.2 Case Study Kindergartens*

Three kindergartens located in Victoria, Australia, are discussed in the following section. One is situated in metropolitan Melbourne and the other two are situated in rural Victoria. The following descriptions provide an overview of the context of the kindergarten and the sessions we attended as part of the professional learning and generation of data.

### *22.6.3 Kindergarten A—Metropolitan Kindergarten*

Kindergarten A is a small kindergarten located in a major metropolitan city. The teaching staff are very experienced and have a long history of working at the kindergarten. Professional learning provided educators with an introduction to Beebots across two sessions. Session 1 was attended by 15 educators and provided them with an introduction to computational thinking, conducting embodied cognition activities including having educators 'program' each other moving around the room, and time to explore the Beebots and how they worked by giving them specific instructions. Educators were unfamiliar with how to use robots with children and this introduction provided the majority of staff with pedagogies and an understanding of how they could use robots in the future. Session 2 was done with 5 educators who participated in the study and provided more specific examples of how Beebots could be utilised in play-based learning in literacy, mathematics, STEM and science. Play-Based Learning was linked to the use of Beebots with specifically designed mats, physical changes to the local environment (e.g. using chalk, wooden blocks, etc.) and relevant scenarios. Isabel (pseudonym) was a lead educator who participated in the study. The children were given the opportunity to play with the Beebots and understand how they worked and how to move them. Over four sessions the researchers visited children while they played with the Beebots in different contexts that were largely educator-led, (1) getting to know how the Beebots worked, where children learned how to program and reprogram the Beebots to move across the floor, (2) Snakes and Ladders game, where the children programmed the Beebots to move across the board, up ladders and down snakes, (3) utilising the Beebots to move through a representation of a city, where the children programmed the Beebots to move along city streets to a final destination, and (4) a STEM challenge, where the children programmed the Beebots to move up and down ramps to see how the changes of forces affected their movements.

### *22.6.4 Kindergarten B—Rural Kindergarten*

Kindergarten B is a small kindergarten located in a rural township with a population of under 1,800 people. The teaching staff are very experienced and have a long history of working at the kindergarten. The professional learning session undertaken with this educator was a hands-on session where previous research (Berson et al., 2019) on effective teaching practice with Beebots was highlighted. This included the introduction to the explanation and use of directional arrows, and children acting out the Beebots' specific directions, before the opportunity to see them in action. Directional arrows, instructions and Beebots were provided to the educator to allow her to become familiar with the resources before introducing them to the children. Robotics had not formed any part of the educator's program so applying technology in this manner was a new teaching approach for the educator. The lead educator at this kindergarten adopted a pedagogical approach that was a balance of child-led discovery and educator-led instruction. It facilitated the opportunity to begin the Beebot lessons with direct instruction on how to apply their Beebot then for the children to spend time playing with the Beebot. Like Cohort A, Session 1 included an introduction to robots, directionality, but not the children acting out the directions, and playing with the robots. In her introduction of the Beebots, the educator drew children's attention to mechanical toys and to 'robots' on television. She used many of the strategies suggested in the professional learning. For example, all children were given the opportunity to set the direction of the Beebot during this introductory session and group conversation ensued about how the Beebot would move. During the sessions that pertained to the Beebots, the children were given the opportunity to play with the robots over two weeks. The children were invited to play with the Beebots in small groups due to the limited number of robots (four) and to discover how they worked. The children were left to explore and use supporting materials to play with the robot that included small plastic farm animals, construction blocks and ramps. Researcher observations indicated that some children were confused about the directional elements of the Beebots. Session 2 revised how Beebots worked and the educator introduced the children to acting out the Beebots' movements. This enabled the children to be more successful in 'playing' with the Beebots. The educator went on to demonstrate how Beebots could be used with mats. A problem solving element was introduced where educators and children imagined destinations that the Beebots had to travel to or obstacles to travel around.

### 22.6.5 Kindergarten C—Regional Kindergarten

Kindergarten C is a medium sized kindergarten located in a regional area with a population of approximately 10,000 people. The teaching staff are very experienced and have a long history of working at the kindergarten. They adopted a child-led discovery approach to their pedagogy and the children often were allowed to free-play whilst learning. Robotics had not formed part of the educator's regular program in the past so for the educators involved, this was a new addition to their program. The professional learning was conducted in an extended session and involved demonstrating the Beebot functionality (as with the rural kindergarten) and ideas for applying them in the classroom. Teaching materials (as above) were provided to the teaching staff. As members of the research team had worked closely with these educators previously on other projects, we determined one session would be sufficient to deliver the necessary information to effectively use the devices. We introduced the educators to the robots and provided them with ideas for their use including directionality, acting out of directions and programming. At the kindergarten, an educator introduced the Beebots to the children. She provided the children with the information and interactions as described in the professional learning session, but emphasised aspects depending on her assessment of children's understanding at the time. For example, she spent considerable time on directionality through children standing and mimicking the commands of the Beebot. The robots were used in a number of sessions and the children were invited to use the robots during free-play time. The children were left to explore and use supporting materials to play within the kindergarten environment with the robot, which included construction blocks and ramps. The kindergarten had a large carpet mat which incorporated a two-dimensional city roadmap which was utilised in the robot play sessions.

### 22.6.6 Research Design

The research design for this project was Action Research, which "provides a process by which changes can be introduced, evaluated and refined in a practical setting" (Greenbank, 2012, p. 147), including early childhood education contexts (Jiang & Zheng, 2021; Ljunggren, 2016). In this study, researchers worked with early childhood educators as research collaborators to work together to effectively implement and then evaluate/reflect, as facilitated by professional learning sessions and discussions in interviews, on the use of Beebots to afford children's learning about STEM through play. This is a design according to which researchers collaborate with participants "in a cyclical process of fact-finding, exploratory action, and evaluation" that "combines participatory action with reflection and theory to co-create practical solutions" (Jiang & Zheng, 2021, p. 249). As Ljunggren (2016) points out, this is an approach to research that highly values the expertise of participants who co-direct the research, with researchers and participants challenging and supporting each other in regard to their existing knowledge and practices to move towards productive changes in this knowledge and practice. As this research unfolded, not only did educators develop new understandings of, and dispositions towards, played-based STEM learning with Beebots, but researchers simultaneously developed new understandings of the nature of such learning and the challenges and affordances of such an approach for educators and children when it comes to STEM.

A case study research approach was adopted as part of this research design. This is a research approach "in which one or a few instances of a phenomenon are studied in depth" (Blatter, 2008, p. 2). It emphasises the in-depth analysis of selected cases in order to understand the contextualised and specific nature of teaching and learning (Blatter, 2008). For this study, this in-depth analysis involved three cases that each related to a different early childhood centre made up of distinct educators and children with varying expectations and experiences with STEM education, play-based learning and tangible coding devices such as Beebots.

## 22.7 Results

In this section, three case studies describe the actions of the children as they were provided with Beebots in play scenarios, as informed by the coding of examples/moments from these three different cases using the IEF. In some instances the application of these codes is more speculative than others, which we further unpack in the discussion. For each case, we firstly report on the sequence of events leading up to the play to contextualise the instances that were observed and then classify these moments according to the IEF that then informs our discussion. In particular, we attempted to include the dispositions and behaviours of the children, which were supported by our observations and educators' comments. Note that all names referred to in this section are pseudonyms.

### *22.7.1 Kindergarten A—Snakes and Ladders*

**Describing the play—STEM learning in action with Beebots**

In this example, the educator had organised a large plastic 'snakes and ladders' game mat to be set up on the floor and secured with masking tape (see Fig. 22.3). The educator, Isabel, had been working with children to teach them the basics of how the

**Fig. 22.3** Children placing the Beebot at the bottom of a ladder on the game mat

Beebots worked, how to start the Beebots, pause them, and clear their programming. Children had been playing with Beebots in their own way and had been briefly introduced to the game of snakes and ladders. Setting up the snakes and ladders mat a second time, Isabel was focussing on mathematics:

> Hopefully they will get the idea of going into the squares and maybe understand...I don't think they've done snakes and ladders before... the game. They can even use the numbers to know where they're going and to recognise numbers. (Educator Interview)

Isabel tried to get the children to start at number 1 as a starting point. A child, Corinne, focused on moving the Beebot to number 10, counting out the steps but entering too many steps. She seemed to enjoy playing with the Beebot by pressing as many buttons as possible and seeing what happened. A second child, Penny, was not interested in moving across the mat but setting her Beebot at the bottom of ladders (see Fig. 22.3). She programmed it without counting the number of steps needed, stopping it before it finished climbing the ladder. Playing with the Beebot, she enjoyed making it turn on the spot in 90 and 180° turns and had a good understanding that it would remember the last commands. Eventually, Penny would count out the steps needed to cross the mat and to climb ladders, but did not make the connection between the size of the squares and rungs on the ladders, sending the Beebot too far. However, she improved in her estimates over time:

> Penny appeared to be getting better at guessing how many steps were needed and when I asked "Where will it stop?" she was able to successfully predict where it would stop by pointing to the final location. (Field Notes, author GA)

Taking the lead from Penny, Corinne joined in wanting to make her Beebot go up a ladder as well. However, she did not count the number of steps that she needed to take and when programming the Beebot she seemed to get enjoyment by programming a high number of steps.

### *22.7.2 Analysing the Play—Applying the IEF*

Together, these two children demonstrated an enjoyment of playing with the Beebots on the snakes and ladders board. The numerical representations assisted with counting of numbers across the mat, although this was also problematic as the squares and rungs represented shorter distances than a single movement of the Beebot. They demonstrated developing mathematics skills as they counted squares across the game mat and rungs up the ladders and entered a number of commands into the Beebot. This proved to be challenging for the children, although Penny had a better understanding of the number of steps required as she developed experience.

The children of Kindergarten A clearly demonstrated forms of **physical embodiment**. In particular, direct embodiment was demonstrated when they used physical representations of the mat (such as grid squares and ladder rungs) and the buttons on the Beebot to support their cognition. **Surrogate embodiment was demonstrated when the children programmed the Beebot to move across the game mat in meaningful ways that represented the way that the children themselves might have moved across the game mat.** In this, they demonstrated developing technology skills, utilising aspects of computational thinking such as algorithmic and logical thinking where they planned the sequence of movements so that the Beebot would successfully move across the game mat to the desired final location.

### *22.7.3 Kindergarten B—Maze Runners*

**Describing the play—STEM learning in action with Beebots**

At Kindergarten B the children were accustomed to playing with wooden construction blocks (see Fig. 22.4). These blocks were readily accessible to the children, who could use them when they wished. The educator, Caroline, began her session by displaying to the children the directional arrows on an A4-sized piece of paper prior to introducing the Beebots. The intention was to build the children's understanding of 'forwards', 'backwards' and '90 degree rotation'. Caroline had the children move in the direction of the arrow that she was holding in her hands. After ten minutes of moving around, Caroline introduced the children to a Beebot. Through discussion,

**Fig. 22.4** Navigating Beebots through the maze

Caroline gave the children the opportunity to make connections between the activity they had just completed and how the Beebot operated. She demonstrated how to 'start' the Beebot, 'stop' it and update its programming. Four Beebots were then placed in one area of the kindergarten, near where the construction blocks were stacked, and the children, in groups of three or four, were given the chance to play with them for ten to fifteen minute intervals. The children were left to their own devices as to how they would play with the Beebots.

> I needed to get knowledge about what their knowledge of robots was...I would scaffold what they know with some extra but I had no idea what their understanding was. It was very varied…With young children what you expect is often not what they understand so I've learned to question. (Educator Interview)

After some play where children worked out how to program the Beebots' movements, a group of four children set about constructing a maze. The initial maze was found to be too restrictive and the Beebots would not move without hitting the walls, so the maze was widened. The children who had constructed the maze were engaged in their play well past their allotted fifteen minutes, and asked to return later in the session and resume their play. The maze was altered by the children as they found different combinations of programming the Beebots to move through the maze. Making the Beebots go through the maze and then return proved to be too complex for the children, who solved the problem by physically picking up the Beebots and turning them around in the maze.

### 22.7.4 Analysing the Play—Applying the IEF

Initially, there was a heightened sense of awareness with directionality (mathematics) as the children spent more time testing and applying the coding (problem-solving and computational thinking) of the Beebots and the children engaged in counting the number of moves needed (mathematics). At times using their hands and arms to determine how far one 'push' of a button would move the Beebots (measurement). The children began to connect the Beebots' movement and mazes they had been making in two ways: (1) they were designing and constructing their maze for a specific purpose in terms of making the Beebots move along a predetermined path (technology), and (2) they were developing specific programming to make the Beebots move through the maze without them having to intervene in the programming.

The children of Kindergarten B clearly exhibited forms of **physical embodiment, surrogate embodiment** and we suggest also possibly **imagined embodiment**. Children demonstrated **direct embodiment as they acted out the movements of the arrows.** The children were using their own bodies to mimic the action of the Beebot's coding buttons (directional arrows). **When the children started to 'play' with the Beebots, they were demonstrating surrogate embodiment as they were relating their earlier movements to the directional arrows on the Beebots. This was also demonstrated as they had to program the Beebots through the maze.** In the latter two instances of surrogate embodiment, there was also **the possibility of imagined embodiment occuring, for example, when the children had to imagine how the Beebots might move in response to the coding.** This is however a speculative suggestion as the children were not questioned and only observed at this point.

### 22.7.5 Kindergarten C—Block Play

**Describing the play—STEM learning in action with Beebots**

At Kindergarten C the children were also accustomed to playing with small wooden construction blocks. The educator, Pamela, began her lesson by showing the children a Beebot and asking what they thought it was. After explaining its functionality, movement, buttons and the concept of coding, the children were given the opportunity to play with the Beebots. With four Beebots available, there was considerable initial enthusiasm across the group, so the children had to be restricted to groups of four to be able to play. There was no explicit educator-determined intention to the play as the educator's pedagogical approach was child-centred, discovery-based learning with occasional educator scaffolding and intervention. The children were left to their own devices as to how they would play with the Beebots.

> We are very much into children exploring so once they know how to work it, we are guided by them. (Educator interview)

The children began to understand the Beebot movement and to build an understanding of its functionality. A group of four children set about using the Beebot to move blocks around such that they became more than just wooden blocks; the blocks had become 'mountains' which needed to be pushed over and out of the way so that the Beebot could progress (see Fig. 22.5). Another group simply wanted to use the Beebot as a machine to relocate the blocks, much like a large vehicle purpose-designed to move large boulders, using the Beebot to push the blocks.

> I found the children grasped the concept of programming the Beebot really quickly. There was a core group that really focussed that did lots of measurement with their hands and how many hands was it to go forwards and how many to sideways. Then I had some children who wanted to push things forwards and knock blocks over and make a bridge but they needed to give it a physical push to make it go. They even decided to make it do leaps! I found that fascinating, they really then wanted the next stage and control it to do more. (Educator Interview)

The children using the Beebots were engaged in their play but grew distracted by the end of their allotted session. Once grasping the workings of the Beebot and its function, the children were looking for the next step and to be challenged further.

**Fig. 22.5** Beebot colliding with wooden blocks

### *22.7.6 Analysing the Play—Applying the IEF*

The moving of the blocks occurred more through discovery and chance than as a purposeful activity. Using the Beebot as tractors to 'ram' the blocks, was a repurposing of the Beebot in an unforeseen way but did indicate some technological thinking of the children. There was a developing sense of direction and distance as the children attempted to code and test the Beebot. Children were engaged in measuring and counting the number of moves (mathematics), at times using their hands and arms to determine how far one 'push' of a button would move the Beebot, and the specific programming making the Beebot move each block.

The children at Kindergarten C clearly demonstrated forms of **physical embodiment and also, we suggest possibly imagined embodiment**. The blocks the children were attempting to move took on different identities for one group—these were much larger structures that represented mountains that were in the way of the Beebot and that the Beebot could not go around, rather had to go through (as a ramming tractor). Children exhibited direct embodiment when they used the wooden blocks to enact a scenario, the relocation of mountains. In addition, as the children began to move around the wooden blocks that had been transformed into mountains and the boulders, they demonstrated augmented embodiment as they applied a system of representations, with blocks representing other structures and features to embody the learner. The unfolding narrative in which the Beebots acted as 'tractors' to move blocks as 'boulders' is suggestive to us of imagined embodiment.

## 22.8 Discussion

In this chapter we have examined children using TCTs in early childhood environments in response to the research question; *How can Bee-bots and robotic devices support and complement children's learning?* Using educator interviews, researcher field-notes and video-recordings we observed their use of TCTs during play.

The nature of play demonstrated in this research involved pairs or small groups of children playing in parallel or constructively as a group, emphasising the benefits of the socio-cultural nature of play (Campbell, 2020). Educators selected play scenarios that were appropriate for use with Beebots and facilitated interactions between children. Generally, children played in small groups of two or three and worked cooperatively. We observed strong elements of engagement in STEM experiences related to problem-solving, mathematical thinking and manipulation, engineering and design construction as children responded to their own play needs. As suggested by Kermani and Aldemir (2015), when the children were engaging in a real task, of interest to them, they undertook their own inquiries and practised a range of STEM skills. The observed play-based learning related to research that highlighted that children's exploration of a new concept was promoted through open-ended play (Edwards, 2017). In particular, we observed elements of what Fleer (2011) described as 'conceptual play' where children's imagination and cognition aligned to develop underlying concepts. It also aligned with the Department of Education and Training Practice Principle—Teaching and Learning Guide as our descriptions highlighted how children "were leading their own learning by exploring, experimenting, investigating and being creative" (DET, 2017, p. 8).

In this study, there were different instances of *physical embodiment,* particularly *direct embodiment* where children utilised their bodies as part of play in physical environments. In the example from Kindergarten A, the utility of the game mats supported play with the Beebots and supported the use of mathematical skills, and elements of computational thinking skills such as decomposition and algorithmic thinking. In the other examples, children were able to manipulate the physical environment to create play scenarios for the Beebots, with this process demonstrating design and thinking skills in the construction of obstacles and mazes that would challenge and accommodate the movement of the Beebots. These latter examples highlighted the fluidity of the kinds of embodied cognition that were realised by children and the overlap with different kinds of play. In the example from Kindergarten C, children were utilising blocks of wood as part of *imaginative* play (Fleer, 2011) where they pretended the blocks of wood were boulders and mountains to serve as obstacles. We suggest that this use of *imaginative* play could be analogous with *imagined embodiment* as proposed by Black et al. (2012), "where an individual also embodies action and perception through imagination" (p. 216). The use of imagined aspects of play focuses on children's perceptions as part of play and could influence the use of TCTs as part of play-based learning as much as aspects of physical embodiment. According to Black et al. (2012), imagined embodiment consists of *implicit* and *explicit* aspects, in the context of this study it is unclear whether pretending (e.g. this wooden block is a boulder) would present a specific focus for children in terms of how play was enacted. At the same time, imagined embodiment focuses on the imagined actions taking place in a particular scenario. In our examples, Beebots were programmed to move across or through a physical space and children's use of imagined (implicit or explicit) embodied cognition may be related to the complexity of the Beebot movements they were planning. It may be that children engaged in imagined implicit embodied cognition when they were trying to move the Beebot across the game mat in the example from Kindergarten A and the final location was not critical to their play. This can be seen where Corinne was more interested in pressing the buttons on the Beebots as many times as she could rather than coding the Beebot to arrive at the final destination. However, when programming the Beebot to pass through a maze or around obstacles, the children's play was more focussed on successful navigation through the physical space to a final destination, which would have required more explicit imagining of the route that the Beebot needed to take. While not the focus of the examples in this chapter, there were instances where the educators attempted to engage children in more explicit planning through using representations of directions (e.g. planning by drawing arrows of the route the Beebot would take). Methods such as this, or by getting children to close their eyes and imagine themselves or the Beebots moving through the physical space, could enhance the use of imagined explicit embodied cognition as part of play-based learning. In suggesting a role for Beebots to afford imagined embodiment, we extend Ioannou's and Ioannou's (2020) use of IEF beyond just physical embodiment when it comes to young children learning from their play with Beebots.

*Surrogate embodiment* is central to the children's use of TCTs in this chapter, but we have utilised this notion in a way that potentially extends how it was originally intended by Black et al. (2012). In each example, children appeared to use Beebots as a representation of themselves to navigate through the physical space, but it is unclear if they intentionally did so and/or realised they were doing so. In the IEF, Black et al. (2012) have focussed on the "learner whereby the manipulation of an external 'surrogate' represents the individual" (p. 216), which is consistent with their focus on screen-based digital technologies whereby the representation on a screen could be directly linked to the child. However, we suggest, following Borghi et al. (2013), that the children in our study may not necessarily be using the TCTs as a representation of themselves passing through the physical space, but more as an extension of themselves as a prosthesis/tool to expand their embodied cognition by extending their body through integration with the physical environment (in this case the Beebots). Borghi et al. (2013) argue that such prostheses/tools are powerful for meaning making because they "enlarge the bodily space of action thus modifying our sense of body" (p. 1), with different tools extending beyond the body and into the environment in different ways that make possible different understandings of this environment. In this way, children using the Beebots to move through the physical space are taking into account situational variables that they themselves can perceive *for* the Beebot and its movements. This may suggest that a broadening of the definition of surrogate embodiment is required in the IEF (Black et al., 2012) for the situation of TCTs, more specifically the positioning of children's use of TCTs as a process of prosthesis/tool formation and enaction as part of an expanded process of embodied cognition (Borghi et al., 2013).

We propose that Beebots can and did afford direct embodiment as well as surrogate embodiment, and show the potential then for facilitating imagined embodiment in the context of play-based learning. In this way, we suggest that Beebots can form part of a learning environment—Black et al. (2012) point out that teaching and learning technologies must be considered as part of the physical makeup of the educational context and so must be considered as part of the learning environment design process—that affords learning and understanding as it makes possible embodied cognition in productive/valuable forms. Our research findings and suggestions are thus in line with those of Ioannou and Ioannou (2020) who also showed the value of different types of embodied cognition for rich student learning experiences.

If we consider the idea of embodied cognition from the stance of play-based learning, we can see that during these observations of embodied cognition, open-ended play did promote children's understandings of new concepts and new ideas (Edwards, 2017). We can see how children used "the body-mind-brain pathways and connections" (Roessingh & Bence, 2018, p. 31) to meaningfully engage with and learn from their play interaction as they were able to physically interact with their material surroundings in ways that enabled engagement with the concepts and ideas in STEM that were the focus of their play. With reference to key STEM ideas, we noted, along with the educators' confirmation, that children used many of the recognised STEM skills of observing, questioning, reflecting on evidence, justifying and communicating during their play with Beebots. While computational thinking skills were noted, children's play also demonstrated some engagement with design technology in the construction of pathways and obstacle courses, science in attempting to move Beebots against gravity up a ramp (relying on the friction of the Beebots wheels on the surface of the plank), and understanding of direction and distance when using the mats.

We observed that the inquiry activities of play with the Beebots, where children were directing and planning their play, did promote children's knowledge construction of coding, mathematics and technology as they collaboratively worked through their experiences (Hedges, 2012). As the Beebots did permit direct and surrogate embodiment in children's playful learning, we support the proposal that children's learning improved through their exploration, experimenting and creation during their direction of their Beebot play.

## 22.9 Limitations and Future Directions

The nature of the intervention may have constrained the expression of embodied cognition by the children involved in these examples. Firstly, Action Research enacts a specific intervention with outcomes observed and then a second cycle is conducted to enact new interventions and enable further feedback (Greenbank, 2012). However, for this research, there was no opportunity for multiple cycles. Secondly, we worked with three kindergartens in Australia with a small number of children so we cannot make broad claims about the findings in this chapter. Thirdly, the children only had a limited amount of time working with the Beebots. Typically, this was a one to two month intervention at each kindergarten with educators who may not have been very experienced in teaching with TCTs.

We suggest that future research that makes use of the IEF needs to consider the way in which TCTs might function as prostheses/tools (Borghi et al., 2013) as part of surrogate embodiment, which involves expanding on Black et al.'s (2012) work and beyond this what counts as embodied cognition in the play-based context of the early-childhood setting. This has to link with research that is exploring the changing makeup of the physical environment in which STEM learning takes place, in order to make sense, through the lens of embodied cognition, of how children can interact in productive ways with TCTs and related technologies that are increasingly present in educational contexts.

Another possibility for future research links with the ideas of *imagined embodiment* which were observed during this research. If we consider some definitions of play that highlight that play is "the creation of an imaginary situation" (Fleer, 2018, p. 1), we can see opportunities for investigating the play situations "where children change the meaning of actions and objects to give them a new sense, and where children work imaginatively to create new meaning through different levels of abstraction" (Fleer, 2018, p. 1). The IEF may be useful for analysing the play where children's action and perceptions are demonstrated in *implicit* and *explicit* ways through imagination.

Not all TCTs are the same. The physical nature of the Beebots, how they are programmed and how they move through physical space impacts on the learning and engagement children have with these technologies. The Beebot lends itself to programming movement by entering in a sequence of commands via buttons, that must be held in the child's memory or are inscribed (e.g. paper or whiteboard) before entry. Complementary TCTs such as *Cubettos*, have a wooden interface where children can use arrows to represent the movement about to be programmed and can see the sequence about to be enacted by the Beebots. This change in the physical nature of the programming allows children to rely less on memory and affords the opportunity to reflect on the symbolic representational nature of the sequence of commands (Murcia & Tang, 2019). Future research could examine how different kinds of physical tools could be utilised to scaffold children moving from exploratory behaviour to challenges that require more sophisticated planning (e.g. cards with arrows on them, roleplaying the movements required, using tape to mark out the path necessary to negotiate a maze). The role of physicality and its influence on embodied cognition could also be examined by examining real (i.e. physical) Beebots versus some sort of digital emulator or other digital representation. This would allow exploration of the influence of the physicality of the robot compared with a digital representation (e.g. computer program or app) which is functionally equivalent, but lacks the immediate presence in a physical space. This would allow examination of the different kinds of embodied cognition highlighted in the IEF.

We argue that it is important to carefully consider the design of learning environments for STEM in early childhood settings, and that this must involve careful consideration of how the various artefacts/tools (e.g. Beebots) can be used for learning and understanding. We propose that this needs to involve a consideration of embodied cognition and links to play-based learning. It seems to us that embodied cognition and play-based learning are tightly intertwined, particularly when it comes to STEM in early childhood settings.

## References

Anwar, S., & Menekse, M. (2021). A systematic review of observation protocols used in postsecondary STEM classrooms. *Review of Education, 9*(1), 81–120.

Baccaglini-Frank, A. E., Santi, G., Del Zozzo, A., & Frank, E. (2020). Teachers' perspectives on the intertwining of tangible and digital modes of activity with a drawing robot for geometry. *Education Sciences, 10*(12), 387–408.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*(1), 617–645.

Bers, M. (2008). *Blocks to robots: Learning with technology in the early childhood classroom.* Teachers College Press.

Berson, I. R., Murcia, K., Berson, M. J., & Damjanovic, V. (2019). Tangible digital play in Australian and US preschools. *Kappa Delta Pi Record, 55*(2), 78–84.

Black, J. B., Segal, A., Vitale, J., & Fadjo, C. (2012). Embodied cognition and learning environment design. In D. Jonassen & S. Lamb (Eds.), *Theoretical foundations of student-centered learning environments* (pp. 198–223). Routledge.

Blatter, J. K. (2008). Case study. In L. M. Given (Ed.), *The SAGE Encyclopedia of qualitative research methods* (pp. 68–72). SAGE Publications.

Borghi, A., Scorolli, C., Caligiore, D., Baldassarre, G., & Tummolini, L. (2013). The embodied mind extended: Using words as social tools. *Frontiers in Psychology, 4*. https://doi.org/10.3389/fpsyg.2013.00214

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77–101.

Brenner, M. E. (2006). Interviewing in educational research. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), *Handbook of complementary methods in education research* (pp. 357–370). Lawrence Erlbaum Associates Publishers.

Campbell, C., Speldewinde, C., Howitt, C., & MacDonald, A. (2018). STEM practice in the early years. *Creative Education Journal Special Edition Preschool Education Research, 9*(1).

Campbell, C. (2020). Learning about STEM. In A. Kilderry & B. Raban (Eds.), *Strong foundations: Evidence informing practice in early childhood*. Publisher ACER (Australian Council for Educational Research). https://research.acer.edu.au/strong-foundations/13/

Campbell, C., & Speldewinde, C. (2020). Affordances for science learning in 'Bush Kinders.' *International Journal of Innovation in Science and Mathematics Education, 28*(3), 1–13.

Çetin, M., & Demircan, H. Ö. (2020). STEM education in early childhood. *Inonu University Journal of the Faculty of Education, 21*(1), 102–117. https://doi.org/10.17679/inuefd.437445

Chan, K. K. (2020). Using tangible objects in early childhood classrooms: A study of Macau pre-service teachers. *Early Childhood Education Journal, 48*, 441–450.

Crawford, B. (2015). Authentic science. In R. Gunstone (Ed.), *Encyclopedia of science education.* Springer. https://doi.org/10.1007/978-94-007-2150-0_144

Department of Education (DET). (2017). *Practice principle guide—Integrated teaching and learning approaches*. https://www.education.vic.gov.au/childhood/professionals/learning/Pages/veyldfproflearn.aspx

Edwards, S. (2016). New concepts of play and the problem of technology, digital media and popular-culture integration with play-based learning in early childhood education. *Technology, Pedagogy and Education, 25*(4), 513–532. https://doi.org/10.1080/1475939X.2015.1108929

Edwards, S. (2017). Play-based learning and intentional teaching: Forever different? *Australasian Journal of Early Childhood, 42*(2), 4–11.

Edwards, S., & Bird, J. (2015). Observing and assessing young children's digital play in the early years: Using the digital play framework. *Journal of Early Childhood Research, 15*(2), 158–173. https://doi.org/10.1177/1476718X15579746

Ferguson, J. P., Aranda, G., Tytler, R., & Gorur, R. (2019). Video research—Purposeful selection from rich data sets. In L. Xu, G. Aranda, W. Widjaja, & D. Clarke (Eds.), *Video-based research in education—Cross-disciplinary perspectives* (pp. 124–139). Routledge.

Final BOTSTEM 01A1 Report. (2017). *Written for the European Commission and Erasmus*. https://www.botstem.eu/wp-content/uploads/2020/11/FINAL-BOTSTEM_O1A1_report.pdf

Flannery, L., & Bers, M. (2013). Let's dance the "Robot Hokey-Pokey!" *Journal of Research on Technology in Education, 46*(1), 81–101. https://doi.org/10.1080/15391523.2013.10782614

Fleer, M. (2011). 'Conceptual Play': Foregrounding imagination and cognition during concept formation in early years education. *Contemporary issues in Early Childhood 12*(3) https://doi.org/10.2304/ciec.2011.12.3.224

Fleer, M. (2017). Digital pedagogy: How teachers support digital play in the early years. In J. Bowen (Ed.), *Digital technologies and learning in the early years* (pp. 114–126). SAGE Publications Ltd.

Fleer, M. (2018). Conceptual playworlds: The role of imagination in play and learning. *Early Years.* https://doi.org/10.1080/09575146.2018.1549024

Fleer, M. (2019). *Play in the early years* (2nd ed.). Cambridge University Press.

Fugate, J. M. B., Macrine, S. L., & Cipriano, C. (2019). The role of embodied cognition for transforming learning. *International Journal of School & Educational Psychology, 7*(4), 274–288.
Gibson, M., & Gunn, L. (2020). The early childhood professional. In A. Kilderry & B. Raban (Eds.), *Strong foundations: Evidence informing practice in early childhood*. Publisher ACER (Australian Council for Educational Research). https://research.acer.edu.au/strong-foundations/13/
Greenbank, P. (2012). Implementing an action research project: A case study in making decisions and managing challenges. *International Journal of Research & Method in Education, 36*(2), 145–161.
Hachey, A. C., An, S. A., & Golding, D. E. (2021). Nurturing kindergarteners' early STEM academic identity through makerspace pedagogy. *Early Childhood Educational Journal*. https://doi.org/10.1007/s10643-021-01154-9
Hayes, J. C., & Kraemer, D. J. M. (2017). Grounded understanding of abstract concepts: The case of STEM learning. *Cognitive Research: Principles & Implications, 2*(7). https://doi.org/10.1186/s41235-016-0046-z
Hedges, H. (2012). Teachers' funds of knowledge: A challenge to evidence-based practice. *Teachers and Teaching: Theory and Practice, 18*(1), 7–24. https://doi.org/10.1080/13540602.2011.622548
Hedges, H., & Cooper, M. (2016). Collaborative meaning-making using video footage: Teachers and researchers analyse children's working theories about friendship. *European Early childhood Education Research Journal*, 398–411. https://doi.org/10.1080/1350293X.2016.1252153
Ioannou, M., & Ioannou, A. (2020). Technology enhanced embodied learning: Designing and evaluating a new classroom experience. *Educational Technology & Society, 23*(3), 81–94.
Jiang, Y., & Zheng, C. (2021). New methods to support effective collaborative reflection among kindergarten teachers: An action research approach. *Early Childhood Education Journal, 49*, 247–258.
Kang, J., Diederich, M., Lindgren, R., & Junokas, M. (2021). Gesture patterns and learning in an embodied XR science simulation. *Educational Technology & Society, 24*(2), 77–92.
Kermani, H., & Aldemir, J. (2015). Preparing children for success: Integrating science, math, and technology in early childhood classroom. *Early Child Development and Care, 185*(9), 1504–1527.
Keune, A., & Peppler, K. (2019). Materials-to-develop-with: The making of a makerspace. *British Journal of Educational Technology, 50*, 280–293.
Levy, D., & Mioduser, S. T. (2010). Making sense by building sense: Kindergarten children's construction and understanding of adaptive robot behaviors. *International Journal of Computers for Mathematics Learning, 15*, 99–127.
Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education*, *7*(11). https://doi.org/10.1186/s40594-020-00207-6
Ljunggren, A. (2016). Multilingual affordances in a Swedish preschool: An action research project. *Early Childhood Education Journal, 44*, 605–612.
Mathayas, N., Brown, D. E., & Lindgren, R. (2021). "I got to see, and I got to be a part of it": How cued gesturing facilitates middle-school students' explanatory modeling of thermal conduction. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21718
Milford, T., & Tippett, C. (2015). The design and validation of an early childhood STEM classroom observational protocol. *International Research in Early Childhood Education, 6*, 24–37.
Moomaw, S. (2013). *Teaching STEM in the early years: Activities for integrating science, technology, engineering, and mathematics*. Redleaf Press.
Murcia, K., Campbell, C., & Aranda, G. (2018). Trends in early childhood education practice and professional learning with digital technologies. *Pedagogika, 68*(3), 249–264.
Murcia, K., & Tang, K. S. (2019). Exploring the multimodality of young children's coding. *Australian Educational Computing, 34*(1), 1–15.
Newhouse, C. P., Cooper, M., & Cordery, Z. (2017). Programmable toys and free play in early childhood classrooms. *Australian Educational Computing, 32*(1), 1–15.
Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1–13.

Phillippi, J., & Lauderdale, J. (2018). A guide to field notes for qualitative research: Context and conversation. *Qualitative Health Research, 28*(3), 381–388.

Pyle, A., & Danniels, E. (2017). A continuum of play-based learning: The role of the teacher in play-based pedagogy and the fear of hijacking play. *Early Education and Development*, 274–289. Published online: 12 Sept 2016

Reinhold, F., Hoch, S., Werner, B., Richter-Gebert, J., & Reiss, K. (2020). Learning fractions with and without educational technology: What matters for high-achieving and low-achieving students? *Learning & Instruction, 65*. https://doi.org/10.1016/j.learninstruc.2019.101264

Roessingh, H., & Bence, M. (2018). Embodied cognition: Laying the foundation for early language and literacy learning. *Language & Literacy, 20*(4), 23–39.

Speldewinde, C., Kilderry, A., & Campbell, C. (2020). Beyond the preschool gate: Pedagogical opportunities in the Australian 'bush kinder'. *International Journal of Early Years Education*, 1–15. https://doi.org/10.1080/09669760.2020.1850432

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education, 26*, 3–20. https://doi.org/10.1007/s10798-015-9304-5

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Weisberg, S. M., & Newcombe, N. S. (2017). Embodied cognition and STEM learning: Overview of a topical collection in CR:PI. *Cognitive Research: Principles and Implications*, 2. https://doi.org/10.1186/s41235-017-0071-6

Wellsby, M., & Paxman, P. M. (2014). Developing embodied cognition: Insights from children's concepts and language processing. *Frontiers in Psychology, 5*, 1–10.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Wilson, R. A., & Foglia, L. (2017). Embodied cognition. In E. Zalta (Ed.), *The Stanford Encyclopedia of philosophy*. https://plato.stanford.edu/archives/spr2017/entries/embodied-cognition/

Wood, E. (2007). Play policy and practice-direction of travel or collision course? *Education, 3–13, 35*(4), 309–320.

Yıldırım, B. (2021). Preschool STEM activities: Preschool teachers' preparation and views. *Early Childhood Education Journal, 49*, 149–162.

# Part VI
# Parents–Families Perceptions and Engagement with Technology

# Chapter 23
# A Comparison of Turkish and Greek Parental Mediation Strategies for Digital Games for Children During the COVID-19 Pandemic

**Stamatios Papadakis, Ali İbrahim Can Gözüm, Michail Kalogiannakis, and Adalet Kandır**

**Abstract** While the pandemic affects the whole world, identifying and comparing its effects in different countries makes an essential contribution to the literature. This study aims to compare the mediation strategies of Greek and Turkish parents for the digital games played by children aged 48–72 months. Parental Mediation Strategies of Digital Games for Children (PMSDGC), developed in Turkey, was used in the study. According to Greek and Turkish participants, the validity and reliability study of the PMSDGC was redone in this study. Data were collected from the data collection tool whose validity and reliability were determined. The study results showed significant differences by country in the mediation strategies used by Turkish and Greek parents for their children. According to parents playing digital games with their children during the pandemic, significant differences were found in the mediation strategy.

**Keywords** Parental mediation · Digital game · Pandemic

## 23.1 Introduction

Today's widespread use of tablets and smartphones has made it easier for children to access mobile applications with touch screens (Zaranis et al., 2013). While children can access many mobile applications using the touch screen, the educational

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aspects of the mobile applications used by children continue to be debated (Papadakis et al., 2018). Although parents and educators want children to develop educationally through mobile applications, it is not easy to evaluate mobile applications with educational content (Papadakis & Kalogiannakis, 2017). Considering children's young age, their parents worry that this challenging situation could be compounded by harmful content such as violence and just educational content (Gözüm & Kandır, 2021). In this regard, parents and teachers alike bear essential responsibilities. During the COVID-19 pandemic, considered one of the biggest problems of our time, children in early childhood necessarily spend most of their time at home. This being so, children at home can use mobile apps possessing harmful content just as they can use apps including educational content (Gözüm & Kandır, 2020a, 2021). Indeed, parents are expected to use parental mediation strategies for their children's mobile apps to benefit from the technology without being exposed to harmful content (Clark, 2011; Kirwil, 2009).

Debate continues regarding children spending more time at home during the COVID-19 pandemic and discussion of the content of their mobile apps. The mediation strategies used by parents for digital games lie at the heart of the solution to this controversial situation and are thus very important. In this regard, identifying the strategies used by the parents of children in early childhood concerning digital games during the COVID-19 pandemic will contribute to the literature and shed light on today's problems. This being so, identifying and comparing the strategies used by parents for digital games in different countries will reveal how the pandemic influences parents' mediation strategies. Comparing the mediation strategies of Turkish and Greek parents for digital games during the COVID-19 pandemic is critical when comparing parents' mediation strategies in different cultures and determining how mediation strategies are used during the pandemic. Based on this, information in the literature about parental mediation concerning digital games will be given briefly. The study's purpose, method, and the working group will be explained.

## 23.2 Literature Review

### *23.2.1 COVID-19 and Technology for Children*

While the COVID-19 pandemic affects the world, it also affects children's daily routines such as early childhood education services, playing games, and spending time in the open. During the COVID-19 pandemic, schools in 188 countries interrupted education, affecting more than 1.5 billion children and young people (UNSDG, 2020). As a result of various restrictions introduced to deal with the pandemic, starting in 2020, Turkey and Greece saw technology turn into a tool for children's education and free time. Despite debates over the use of technology in early childhood, the pandemic has increased technology interaction by necessarily providing children with online learning content and materials (Dias et al., 2020;

Tarrant & Nagasawa, 2020). During the pandemic, parents turned to mobile applications to meet their children's educational needs, and various technological tools tried to meet the educational needs of children. In this regard, Papadakis and Kalogiannakis (2020) examined the educational value of mobile applications. According to the results of their study, they found that most of the applications that claimed to be educational were not educational. However, parents want to use technology to keep their children away from the adversities of the pandemic. The touch screen surfaces of smart mobile devices facilitate preschoolers' use of technological tools (Blackwell et al., 2016). The specialized tools that have increased with touch screens have also led to an increase in mobile educational applications for children in early childhood (Papadakis & Kalogiannakis, 2017). In this regard, children can easily use technological tools without adult assistance. Accordingly, this research question was created: *How do children play digital games during the COVID-19 pandemic in Greece and Turkey?*

It has been determined that the increase in the time children spend playing digital games has resulted in harmful effects on the development of children (Steinkuehler, 2010). Since children who were already familiar with digital tools before the pandemic spend time in front of the screen is a source of concern for parents, they can take precautions for the time their children spend in front of the screen (Gözüm & Kandır, 2020a). The time spent in front of the screen, while protecting the sense of normalcy by meeting children's learning and entertainment needs during the pandemic, becomes a fundamental paradox for parents (UNICEF, 2020). Naturally, this paradox made the researchers ask *How long children played digital games during the COVID 19 pandemic in Greece and Turkey?* Gentile et al. (2012) reported that digital games cause focusing problems in children. The study by Gözüm and Kandır (2020a) reported that children's inclination to play games decreased due to the increase in time spent playing digital games. However, the researchers are aware that various factors in answer to this question positively or negatively affect children. For example, even if the time spent by children in front of the screen is short, when there is no parental mediation, a significant hostile environment is created for children who face online risks such as violent and illegal content and pornographic pop-up advertisements (Bluemke et al., 2010; OECD, 2020; Wack & Tantleff-Dunn, 2009). In another example, as a result of deliberate parental guidance, a learning environment can be created that supports children's learning in a specific period (Bolstad, 2004; Clements & Sarama, 2003; Guernsey et al., 2012; Hatzigianni & Margetts, 2012; Jack & Higgins, 2019; McCarrick & Li, 2007; McKenney & Voogt, 2012; Nikolopoulou & Gialamas, 2015; Papadakis et al., 2016; Vaughan & Beers, 2017). The study conducted by Gözüm and Kandır (2021) examined the content of digital games played by children in early childhood and the mediating roles of parents. It was determined that 90% of the parents do not deliberately mediate digital games. It is understood that in the absence of deliberate mediation, children play violent and neutral games. Deliberate mediation supports children's learning and an online environment free of risk factors. The parental mediation strategies in this regard are described below.

### 23.2.2 Parental Mediation Strategies

Parental mediation is the restriction, monitoring, and guidance of parents against the negative aspects of technology when various technological tools are used by children (Warren, 2001). Parental mediation strategies differ according to the media tool (television, internet, digital game) (Beyens et al., 2019). The study by Gözüm and Kandır (2020b) on children aged 48–72 months determined that parents in Turkey use viewing mediation, laissez-faire mediation, technical mediation, restrictive mediation, and active mediation co-playing mediation strategies for digital games. *Considering mediation* can be defined as parents' control and observation for digital games suitable for children's developmental level (Hasebrink et al., 2011; Livingstone & Helsper, 2008; Livingstone et al., 2015; Valkenburg et al., 1999). *Laissez-faire mediation* is not a parent mediation strategy per-se but means that parents do not deliberately act as a mediator when children play digital games (Gözüm & Kandır, 2020b). *Technical mediation* is a type of mediation in which parents protect their children from various risks by applying multiple technical restrictions such as software, passwords, or filters developed in line with the experts' recommendations to the digital tools where digital games are played (Livingstone & Helsper, 2008). *Restrictive mediation* is a type of mediation in which the parent restricts the digital game played by the child because of negative aspects or situations that negatively affect children in the digital games they play (Livingstone et al., 2015). *Active co-playing mediation strategy* is mediation derived from the nature of the digital game. When playing digital games, the parent and child stay in touch and interact using the active mediation strategy. They play the digital game together in contact with one another. In this context, both the child and the parent use the *active co-playing mediation strategy* in the digital game (Hasebrink et al., 2011; Livingstone & Helsper, 2008; Nikken & Jansz, 2014).

Parental mediation strategies reduce the use of media that will pose a risk to children (Atkin et al., 2006). Mesch (2009) reported that the risk of being exposed to cyberbullying decreases for the children of parents who use the active mediation strategy. Livingstone and Helsper (2008) found that the restrictive parent mediation strategy reduces online risks. In the study conducted by Gözüm and Kandır (2021), it was determined that parents who positively support the development of children aged 60–72 months used the *active co-playing mediation* strategy. The results showed that situations pose a risk to children or are positively affected by technology use for a single country. However, Livingstone et al., (2017, p. 99) suggest that the mediation strategies used by parents may vary from country to country and from culture to culture. This makes it extremely important to compare the parental mediation strategies for digital games adopted by parents from different cultures and countries. It is thought that examining the mediation strategies used by parents in other countries, particularly during the COVID-19 pandemic, will significantly support the literature. This led the researchers to ask *whether there is a significant difference between the* *viewing mediation, laissez-faire mediation, technical mediation, restrictive mediation, and active co-playing mediation strategies of Turkish and Greek parents during the COVID-19 pandemic?*

The American Academy of Pediatrics recommends that parents adopt the active co-playing mediation strategy when playing digital games with high-quality educational content for their children (American Academy of Pediatrics [AAP], 2013). On the other hand, Nikken and Jansz (2014) found that parents use restrictive strategies to keep children away from online risks and active and co-playing mediation strategies to support positive development. Given both the AAP recommendation and the research results (Gözüm & Kandır, 2021; Nikken & Jansz, 2014), the researchers asked this research question: *Is there a significant difference between the mediation strategies used by parents who play digital games with their children during the pandemic and those who do not?* This research question reveals how the different types of parental mediation used for children are affected when parents stay home during the pandemic. It is also essential to check whether this situation differs significantly according to the country variable. This poses the question: *Do the parent mediation strategies used by parents who play and do not play digital games with their children during the pandemic process differ significantly according to the country variable?*

### *23.2.3 The Present Study*

This study aims to compare the mediation strategies of Greek and Turkish parents for the digital games played by children aged 48–72 months. To this end, the following research questions were formed:

- How long do children play digital games during the COVID 19 pandemic in Greece and Turkey?
- Children play digital games on which devices during the COVID-19 pandemic in Greece and Turkey?
- Is there a significant difference between Turkish and Greek parents viewing mediation, laissez-faire mediation, technical mediation, restrictive mediation, and cooperative play mediation strategies?
- Is there a significant difference between the mediation strategies used by parents who play and do not play digital games with their children during the pandemic?
- Do the mediation strategies used by parents who play and do not play digital games with their children during the pandemic process differ significantly by country?

## 23.3 Method

This study uses the relational screening method based on quantitative research methods. The relational screening method is a research model that aims to determine the relationship between two or more variables and the degree of this relationship (Karasar, 2009).

### *23.3.1 Working Group*

A working group was created using criterion sampling, a research objective sampling method (Büyüköztürk et al., 2012). Two criteria were adopted for the participants in the working group. The first criterion is the voluntary participation of parents with children aged 48–72 months, and the second criterion is that children play digital games during the COVID-19 period. The study's working group consists of parents living in Greece and Turkey. Greek parents were included in the study by Greek researchers, and Turkish parents were included in the study by Turkish researchers according to their fulfillment of the criteria. Table 23.1 shows the demographic values of the gender and education levels of the Greek and Turkish Parents participating in the study.

According to Table 23.1, 260 parents from Greece participated in the study. 85.8% ($n = 223$) of the parents were male and 14.2% ($n = 37$) were female. 48.8% of the parents have a bachelor's degree. Six hundred thirty parents from Turkey participated in the study. 35.6% ($n = 224$) of the parents were male and 64.4% ($n = 406$) were female. 38.6% of the parents have a bachelor's degree. Table 23.2 shows the demographic information regarding the gender and age groups of the children participating in the study.

According to Table 23.2, 45.8% ($n = 119$) of the study participants from Greece were girls, and 54.2% ($n = 141$) were boys. 74.6% ($n = 194$) of the children were between the ages of five and six, and 25.4% ($n = 66$) were between four and five. 52.9% ($n = 333$) of the children participating in the study from Turkey were girls, and 47.1% ($n = 297$) were boys. 59.0% ($n = 566$) of the children are between the ages of five and six, and 41.0% ($n = 324$) are between four and five.

### *23.3.2 Data Collection Tool*

This study uses the Parental Mediation Scale of Digital Games for Children (PMSDGC) scale developed by Gözüm and Kandır (2020b). The PMSDGC has a five-factor structure. Exploratory factor analysis (EFA) shows that the scale factors are: viewing mediation, laissez-faire mediation, technical mediation, restrictive mediation, and cooperative play mediation. Confirmatory Factor Analysis (CFA) was applied to the scale using different samples possessing the same psychometric properties. CFA fit index values for the five-factor structure of the scale ($\chi^2 = 1518.070$; sd = 719; $p = 0.000$) are $\chi^2$/sd = 2.11 and less than 3. RMSEA = 0.057; GFI = 0.914; AGFI = 0.918; CFU = 0.886; NFI = 0.906. The ($\chi^2$/sd) value of less than 3 is perfectly concordant (Jöreskog & Sörbom, 1984). RMSEA value is 0.057 and

**Table 23.1** Demographic information of parents participating in the study

| Country | | Parent's gender | | Parent's educational level | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Male | Female | Primary school | Secondary school | High school | Bachelor's | Masters | Doctorate | Total |
| Greece | *n* | 223 | 37 | – | 2 | 69 | 127 | 55 | 7 | 260 |
| | % | 85.8 | 14.2 | – | 0.8 | 26.5 | 48.8 | 21.2 | 2.7 | 100 |
| Turkey | *n* | 224 | 406 | 36 | 61 | 222 | 243 | 27 | 41 | 630 |
| | % | 35.6 | 64.4 | 5.7 | 9.7 | 35.2 | 38.6 | 4.3 | 6.5 | 100 |
| Total | *n* | 447 | 443 | 36 | 63 | 291 | 370 | 82 | 48 | 890 |
| | % | 50.2 | 49.8 | 4.0 | 7.1 | 32.7 | 41.6 | 9.2 | 5.4 | 100 |

**Table 23.2** Demographic information of the children participating in the study

| Country | | Child gender | | Child age group | | Total |
|---|---|---|---|---|---|---|
| | | Girl | Boy | 4–5 years old | 5–6 years old | |
| Greece | *n* | 141 | 119 | 66 | 194 | 260 |
| | % | 54.2 | 45.8 | 25.4 | 74.6 | 100.0 |
| Turkey | *n* | 333 | 297 | 258 | 372 | 630 |
| | % | 52.9 | 47.1 | 41.0 | 59.0 | 100.0 |
| Total | *n* | 474 | 416 | 324 | 566 | 890 |
| | % | 53.3 | 46.7 | 36.4 | 63.6 | 100.0 |

shows concordance (Hu & Bentler, 1998). The NFI value is 906 and shows concordance (Tabachnick & Fidell, 2013). The CFI value is 886. The GFI value is 914 and shows concordance (Hooper et al., 2008). The AGFI value is 918 and shows concordance perfectly (Hooper et al., 2008). The IFI value is 984 and shows concordance (Marsh & Hau, 1996). When the concordance values of the scale are examined, it is understood that the scale has acceptable concordance values.

When the reliability values of the data collection tool regarding the internal consistency are examined, it can be said that " PMSDGC" ($\alpha = 0.813$) and its sub-factors are a reliable measurement tool in terms of internal consistency since Cronbach's Alpha ($\alpha$) values are more significant than 0.70 (Murphy & Davidshofer, 1994). A 5-point Likert scale was used to respond to the items on the scale. Likert expressions included in the scale are scored as follows: Never 1 point, Rarely 2 points, Sometimes 3 points, Frequently 4 points, Always 5 points. Parents can achieve a minimum of 40 points and 200 points from the scale.

In this study, since the data collection tool was applied in a different country, the validity and reliability analyses were made again, and the factor structure was tested. EFA was performed with the data of the Greek parents participating in the research, and CFA was performed with the data of the Turkish parents.

### *23.3.3 Validity and Reliability Study of the Data Collection Tool*

The validity and reliability studies are explained below, in turn.

#### 23.3.3.1 Validity and Reliability Information of the Data Collection Tool of the Greek Study Group

The Greek working group rediscovered the construct validity of the PMSDGC scale. The Kaiser–Meyer–Olkin (KMO) value was examined to see the suitability of the sample size of the dataset belonging to the Greek working group.

The normal distribution of the dataset was determined according to the Barlett Sphericity coefficient. The KMO and Barlett Sphericity coefficients are given in Table 23.3.

According to Table 23.3, the Kaiser-Mayer-Olkin (KMO) value is 0.906, and the Barlett test of Sphericity value is 5594.397. For EFA, the sample size is suitable because the KMO value is more significant than 0.50. The Bartlett Test of Sphericity value ($p = 0.000$, $p < 0.001$) differs significantly (Tabachnick & Fidell, 2013). According to Kaiser (1974), since the KMO Value is more significant than 0.90, the sample size is "very good." The dataset shows normal distribution according to Bartlett's Test of Sphericity values. Accordingly, the dataset is suitable for EFA.

The factor number of the scale is 5. To examine the suitability of the factor number of the 5-factor scale, the Kaiser criterion (eigenvalues $\geq$ 1), scree plot test, and total explained variance can be examined (Hair et al., 1995). In this context, EFA analysis was performed by fixing the number of factors to 5 in the original scale. The percentage of variance explained for the 5-factor structure and the values of the eigenvalue coefficient are seen in Table 23.4.

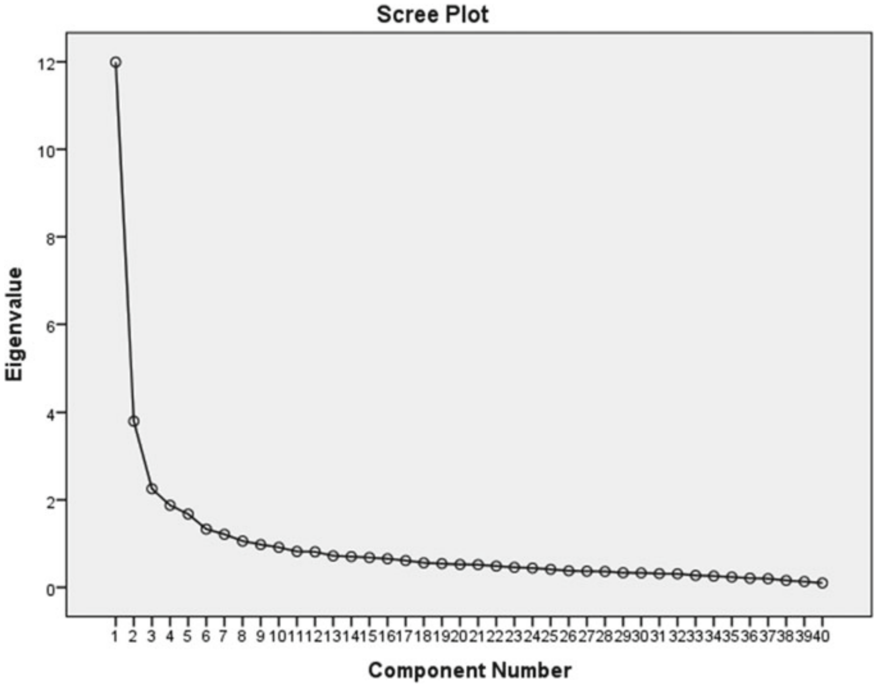
The scree plot was also examined for the suitability of the five-factor measurement tool's factor number. According to Table 23.4, it was determined that the eigenvalue coefficient of the components after the oblimin rotation process was 1, and the number of components greater than 1 was 5. The variance of the five-factor scale is 53.99%. According to Kline (2016), the ratio of the variance explained by the measurement

**Table 23.3** Kaiser Meyer Olkin (KMO) coefficient and Bartlett's sphericity test values

| | | |
|---|---|---|
| Kaiser-Mayer-Olkin (KMO) coefficient | | 0.906 |
| Bartlett's sphericity test values | Approximate chi-square value | 5594.397 |
| | Sd | 780 |
| | *p* | 0.000 |

**Table 23.4** Total explained variance and eigenvalues of components after rotation

| Components | Eigenvalues | Variance % | Cumulative % |
|---|---|---|---|
| 1 | 11.994 | 29.984 | 29.984 |
| 2 | 3.798 | 9.494 | 39.479 |
| 3 | 2.253 | 5.633 | 45.112 |
| 4 | 1.877 | 4.691 | 49.803 |
| 5 | 1.676 | 4.190 | 53.993 |




**Graph 23.1** Scree plot

tool is over 40%, appropriate for the explained variance. The Scree Plot is given in Graph 23.1.

According to Graph 23.1, the number of components above 1 of the eigenvalue load is 5. The factor structure consisting of 5 components has a high slope. In the scree plot, it is necessary to determine the breaking point of the components descending from the high slope. According to Cattell (1978), the dataset must consist of at least 200 people when determining the breaking point. The number of Greek parents participating in the study is 260. The dataset size, which is the breaking point criterion, is provided in the graph. According to Yong and Pearce (2013), the intersection of the horizontal and vertical axes gives the cutoff point when education decreases. According to Graph 23.1', the cutoff point is suitable for the 5-factor structure.

The distribution of the factors items was examined to check the suitability of the items belonging to the five-factor structure with the theoretical structure of the original scale. In this context, the oblimin rotation technique was used as the rotation technique applied to the original form of the measuring tool. 0.4 was set as the lower limit for the item factor loading value for the items to which the rotation technique was applied. The aim of setting the sub-factor load value in the study at 0.40 was to determine the separation of factors more clearly (Rummel, 1988; Yong & Pearce, 2013). Items with a factor load value below 0.40 were examined. Whether or not there was overlap between the items was also discussed. The distribution of the items under the factors following the oblimin rotation technique is given in Table 23.5.

When Table 23.5 is examined, it can be seen that the factors in the (PMSDGC) scale developed by Gözüm and Kandır (2020b) viewing mediation, laissez-faire mediation, technical mediation, restrictive mediation, and active co-playing mediation are theoretically under the same factors.

**Table 23.5** Factor load values of the scale items following oblimin rotation technique and item analysis

| Factor | No | Factor load values of the scale items | | | | | Item analysis values | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F1 | F2 | F3 | F4 | F5 | $r$ | $X$ | 27%($X$) LG | 27%($X$) UG | $t$ | $p$ |
| Viewing (F1) | M01 | 0.646 | −0.014 | −0.217 | 0.087 | 0.284 | 0.587 | 4.21 | 3.40 | 4.69 | 7.722 | 0.000*** |
| | M02 | 0.609 | 0.052 | −0.056 | 0.132 | 0.132 | 0.520 | 4.23 | 3.44 | 4.71 | 7.427 | 0.000*** |
| | M03 | 0.604 | 0.078 | −0.118 | 0.244 | 0.246 | 0.616 | 4.17 | 3.36 | 4.70 | 8.788 | 0.000*** |
| | M04 | 0.651 | 0.231 | −0.142 | 0.109 | 0.062 | 0.640 | 4.51 | 4.00 | 4.87 | 7.247 | 0.000*** |
| | M05 | 0.529 | 0.317 | −0.313 | 0.056 | −0.004 | 0.592 | 4.41 | 3.93 | 4.71 | 5.925 | 0.000*** |
| | M06 | 0.756 | 0.381 | −0.156 | 0.058 | 0.041 | 0.771 | 4.57 | 3.93 | 4.91 | 8.985 | 0.000*** |
| | M07 | 0.725 | 0.335 | −0.129 | 0.005 | −0.055 | 0.698 | 4.62 | 4.16 | 4.89 | 5.872 | 0.000*** |
| | M08 | 0.607 | 0.369 | −0.145 | 0.033 | 0.042 | 0.660 | 4.32 | 3.64 | 4.77 | 7.988 | 0.000*** |
| | M09 | 0.603 | 0.315 | −0. 091 | 0.076 | 0.159 | 0.623 | 4.68 | 4.10 | 4.96 | 6.695 | 0.000*** |
| | M10 | 0.586 | 0.177 | −0.203 | 0.267 | 0.120 | 0.641 | 4.20 | 3.53 | 4.80 | 8.722 | 0.000*** |
| | M11 | 0.490 | 0.293 | −0.153 | 0.140 | 0.083 | 0.600 | 4.36 | 3.80 | 4.80 | 8.057 | 0.000*** |
| | M12 | 0.432 | 0.298 | −0.105 | 0.390 | 0.232 | 0.602 | 4.12 | 3.39 | 4.71 | 9.906 | 0.000*** |
| | M13 | 0.418 | 0.269 | −0.039 | 0.359 | 0.210 | 0.553 | 3.60 | 2.57 | 4.51 | 11.814 | 0.000*** |
| Laisse Faire (F2) | M14 | 0.042 | 0.465 | −0.025 | 0.024 | 0.138 | 0.486 | 2.70 | 3.33 | 4.01 | 4.141 | 0.000*** |
| | M15 | −0.199 | 0.568 | 0.002 | −0.110 | 0.077 | 0.502 | 2.53 | 1.73 | 3.73 | 5.145 | 0.000*** |
| | M16 | −0.188 | 0.730 | 0.088 | −0.026 | 0.063 | 0.651 | 1.90 | 1.01 | 3.16 | 6.775 | 0.000*** |
| | M17 | −0.352 | 0.545 | 0.102 | −0.114 | 0.153 | 0.516 | 1.78 | 1.05 | 2.84 | 7.269 | 0.000*** |
| | M18 | 0.084 | 0.672 | −0.145 | 0.076 | −0.049 | 0.496 | 1.77 | 1.10 | 2.35 | 1.448 | 0.000*** |
| | M19 | −0.046 | 0.735 | −0.189 | −0.039 | −0.115 | 0.617 | 2.30 | 1.44 | 3.39 | 6.338 | 0.000*** |
| | M20 | −0.367 | 0.660 | −0.078 | −0.088 | 0.046 | 0.660 | 1.80 | 1.07 | 2.80 | 5.003 | 0.000*** |
| | M21 | −0.170 | 0.701 | −0.248 | −0.035 | −0.030 | 0.615 | 1.97 | 1.17 | 3.94 | 6.440 | 0.000*** |
| | M22 | −0.126 | 0.674 | −0.322 | −0.045 | −0.057 | 0.593 | 1.88 | 1.13 | 2.90 | 5.587 | 0.000*** |
| | M23 | −0.065 | 0.567 | −0.195 | 0.067 | 0.039 | 0.452 | 1.50 | 1.03 | 2.06 | 7.303 | 0.000*** |
| Technic al (F3) | M24 | 0.267 | 0.048 | 0.416 | 0.118 | −0.113 | 0.397 | 3.30 | 2.19 | 4.16 | 8.371 | 0.000*** |
| | M25 | 0.076 | 0.173 | 0.664 | 0.128 | 0.145 | 0.550 | 3.02 | 2.13 | 4.21 | 9.871 | 0.000*** |
| | M26 | 0.142 | 0.145 | 0.841 | 0.091 | 0.047 | 0.704 | 2.91 | 1.84 | 4.53 | 13.376 | 0.000*** |
| | M27 | 0.132 | 0.131 | 0.828 | 0.083 | 0.045 | 0.656 | 2.71 | 1.86 | 4.00 | 10.464 | 0.000*** |
| Restrictive (F4) | M28 | 0.132 | 0.059 | −0.140 | 0.504 | 0.085 | 0.593 | 4.26 | 3.49 | 4.73 | 8.667 | 0.000*** |
| | M29 | 0.293 | −0.068 | −0.045 | 0.637 | 0.130 | 0.636 | 4.63 | 4.13 | 4.84 | 5.381 | 0.000*** |
| | M30 | 0.256 | 0.143 | −0.200 | 0.631 | 0.171 | 0.647 | 4.46 | 3.89 | 4.84 | 7.714 | 0.000*** |
| | M31 | 0.359 | 0.022 | −0.121 | 0.589 | 0.199 | 0.655 | 4.39 | 3.70 | 4.84 | 7.944 | 0.000*** |
| | M32 | 0.341 | −0.112 | −0.084 | 0.634 | 0.180 | 0.626 | 4.50 | 3.84 | 4.80 | 5.694 | 0.000*** |
| | M33 | 0.258 | 0.100 | −0.010 | 0.515 | 0.360 | 0.555 | 4.07 | 3.43 | 4.61 | 8.798 | 0.000*** |
| | M34 | 0.139 | 0.175 | −0.238 | 0.580 | 0.090 | 0.557 | 4.38 | 3.91 | 4.70 | 5.951 | 0.000*** |
| | M35 | 0.139 | 0.218 | −0.251 | 0.499 | 0.122 | 0.516 | 4.15 | 3.61 | 4.60 | 7.014 | 0.000*** |
| | M36 | 0.203 | 0.237 | −0.161 | 0.627 | 0.199 | 0.616 | 4.26 | 3.56 | 4.69 | 7.678 | 0.000*** |
| Active co-playing (F5) | M37 | 0.148 | 0.124 | −0.081 | 0.098 | 0.850 | 0.800 | 3.59 | 2.74 | 4.31 | 9.418 | 0.000*** |
| | M38 | 0.186 | 0.180 | −0.049 | 0.082 | 0.883 | 0.877 | 3.62 | 2.80 | 4.33 | 9.155 | 0.000*** |
| | M39 | 0.165 | 0.198 | −0.008 | 0.115 | 0.872 | 0.864 | 3.56 | 2.74 | 4.29 | 9.643 | 0.000*** |
| | M40 | 0.090 | 0.223 | 0.015 | 0.105 | 0.853 | 0.822 | 3.57 | 2.80 | 4.26 | 8.308 | 0.000*** |
| Factor | | | | F1 | | F2 | | | F3 | F4 | F5 | Scale |
| Cronbach's alpha ($\alpha$) | | | | 0.900 | | 0.812 | | | 0.747 | 0.865 | 0.932 | 0.865 |

*L.G* Lower group, *U.G* Upper group

#### 23.3.3.2 Second Stage: Findings Related to Item Analysis and Reliability

The item analysis findings regarding the item-total correlation, item discrimination, and internal consistency of sub-factors of "*PMSDGC*" are given in Table 23.5.

*Internal consistency*: Measurement tool and factors*'* Cronbach's Alpha ($\alpha$) values: Internal consistency coefficient of the measurement tool ($\alpha = 0.865$), viewing mediation ($\alpha = 0.900$), laissez-faire mediation ($\alpha = 0.812$), technical mediation ($\alpha = 0.747$), restrictive mediation ($\alpha = 0.865$), active co-playing mediation ($\alpha = 0.932$). It is considered a reliable measurement tool in terms of internal consistency since this value is greater than 70 (Murphy & Davidshofer, 1994).

*Item discrimination*: Item discrimination for the items of the "*PMSDGC*" factors is the power to distinguish the mediation strategies of parents with high scores in the relevant factor and those with low scores. According to Kalaycı (2008), item discrimination can be examined by applying the independent *t*-test to the items of parents separated into the upper 27% and lower 27% of the mediation strategies. Item discrimination for the "*PMSDGC*" factors was examined using an independent *t*-test. All of the items under the factors were found to show a significant difference with a level of $p < 0.001$. In this context, the items in the measurement tool can distinguish parents' mediation strategies between high and low.

*Item total correlation (r) refers to the relationship between the item and the "PMSDGC"* factors factor. Suppose the *r*-value is less than 0.30 ($r < 0.30$), it is a low-level relationship; if the *r* value is between 0.30 and 0.70, it is a moderate-level relationship; if the *r* value is greater than 0.70, the item has a high-level relationship with the factor (Büyüköztürk et al., 2012; Tavsancıl, 2005). According to Table 23.5, item 6 is an example of the viewing mediation factor with a high-level relationship ($r = 0.771$) (*I keep track of whether my child plays dangerous games for children or not*). Item 20 is an example of the laissez-faire mediation factor with a moderate level ($r = 0.660$) relationship (*My child has started to play digital games out of my control*). Item 26 is an example of the technical mediation factor with a high-level ($r = 0.704$) relationship (*I install filter software on the digital device so that my child does not play digital games that I find harmful*). Item 31 is an example of the restrictive mediation factor with a moderate-level ($r = 0.655$) relationship (*I prohibit my child from playing digital games that I think are harmful to their development*). Item 38 is an example of the active co-playing mediation factor with a high-level ($r = 0.877$) relationship (*I explain the digital games that support my child's concept development by playing together*).

#### 23.3.3.3 Reliability Information for the Data Collection Tool of the Turkey Working Group

The (PMSDGC) scale was developed by Gözüm and Kandır (2020b). A dataset of 630 Turkish parents from among the participants was used to confirm its five-factor structure.

CFA fit index values; ($\chi^2 = 2159.150$; sd = 730; $p = 0.000$) $\chi^2$/sd = 2.957, which is less than 3. RMSEA = 0.055; NFI = 0.903; CFI = 0.950; GFI = 0.912; AGFI = 0.880; IFI = 0.950. A (s2/sd) value below 5 indicates a perfect fit (Jöreskog & Sörbom, 1984). Its RMSEA value is 0.055 and it shows good fit (Hu & Bentler, 1998). Its NFI value is 0.923 and CFI value is 0.950, which shows good fit (Tabachnick & Fidell, 2013). Its GFI value is 0.912, which shows a good fit (Hooper et al., 2008). Its AGFI value is 0.880, which shows an acceptable fit (Hooper et al., 2008). Its IFI value is 0.923, which shows good fit (Marsh & Hau, 1996).

According to Fig. 23.1, the items are placed under the relevant factors at the ($p <$ 0.001) level is significant. Based on this, the construct validity of the measurement tool was verified without making any modifications.

The internal consistency coefficients for the total size of the measurement tool answered by Turkish participants are ($\alpha = 0.895$), viewing mediation ($\alpha = 0.912$), laissez-faire mediation ($\alpha = 0.850$), technical mediation ($\alpha = 0.780$), restrictive mediation ($\alpha = 0.845$ active co-playing mediation ($\alpha = 0.920$).

### *23.3.4 Data Collection*

The data were collected using the Google form created by the researchers in Turkish and Greek using Google Form. The Google form included the purpose of the study and ethical notification and a consent form for participating in the study. The researchers shared e-mail addresses on the Google form to communicate with the participants. After the participants completed the consent form saying that they were participating in the study voluntarily, they filled out the data collection tool. The participants used e-mail to ask the researchers questions and clarify anything they did not understand. The researchers gave the relevant answers to the questions sent in by e-mail. All items were filled in because saving without filling in the items on the Google form was used.

### *23.3.5 Data Analysis*

Data analysis in the study was carried out in two stages. The first stage included the validity and reliability analyzes of the data. In the second stage, analyzes were made regarding the findings of the questions on the present study.

The dataset of the Greek participants was subjected to EFA. In contrast, the dataset of Turkish participants was subjected to CFA analysis. Item total correlation, item discrimination, and internal consistency analyses were performed on the EFA dataset. Internal consistency was made to the dataset of Turkish participants. For the problem status of the study, the MANOVA test was conducted to examine the frequency, percentage, mean, standard deviation, and significant differences of the dependent variables over the independent variable to describe the data.

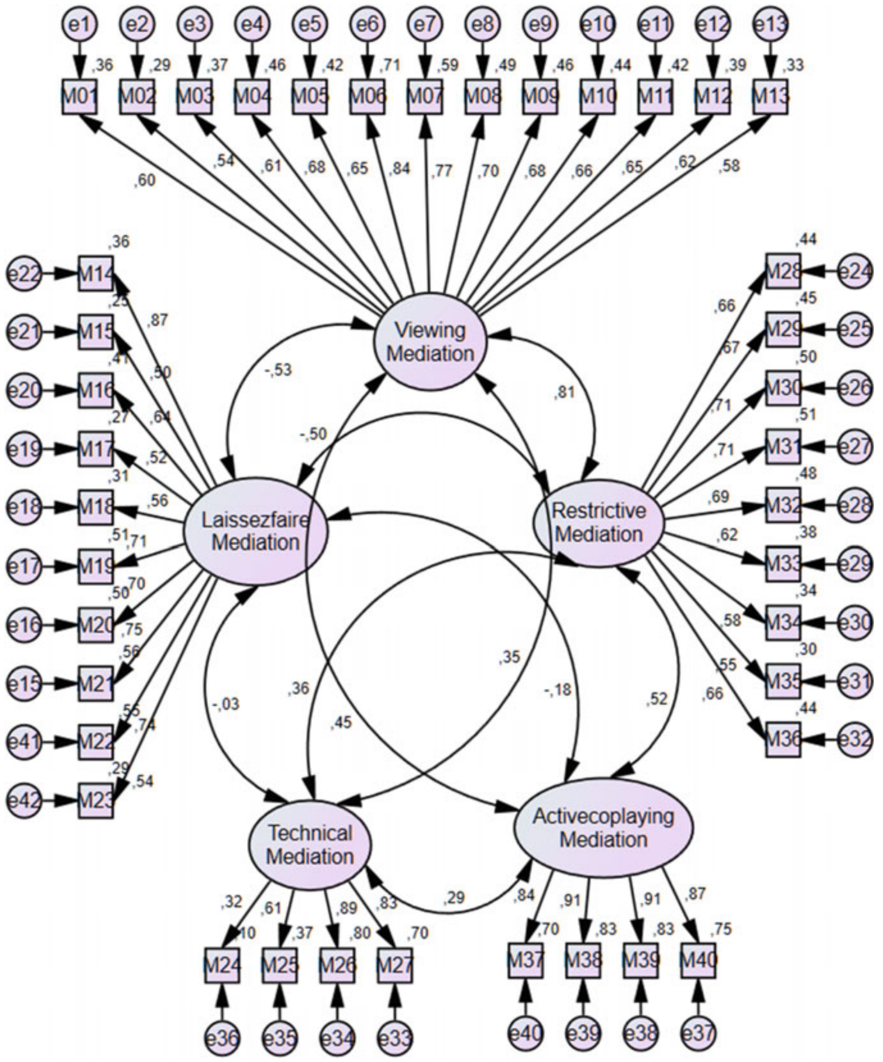



**Fig. 23.1** CFA analysis standard estimates values

## *23.3.6 Data Analysis Assumptions*

When analyzing the data, the assumptions of the EFA, CFA, and MONOVA tests were examined.

When performing the EFA, the normal values of the dataset created by the Greek parents were examined. The total size and each sub-dimension of the dataset were converted into standard *z*-scores. The standard score range of total dimension and sub-dimension is $-3 < z < +3$. The skewness value of the dataset is $-0.125$. The kurtosis value was determined to be 0.217. The kurtosis and skewness coefficients of the dataset are within the limits of ±1. When the ratio of the kurtosis and skewness values to their standard errors was examined, it was determined that they did not exceed ±2. This gives information about the normal distribution of the dataset according to the descriptive statistics results in normality assumption examinations (Abbott, 2011; Gnanadesikan, 1997; McKillup, 2012).

Multiple normality distributions were examined for CFA analysis. It was determined that the multivariate kurtosis value was 2.100, and the CR value was 8.752. It was determined that the CR value was below 10, and the kurtosis value was within the limits of ±3. In this context, it can be argued that the CFA dataset meets the multiple normality assumption (Gürbüz, 2019).

When performing the MANOVA test, the equality assumption of the variance–covariance matrix was tested (Box's $M$ test). It was determined that the variance covariances between the dependent variables (country and playing digital games with their children) were equal for both variables [Box's $M = 24.250$, $F = 1.250$, $sd_1 = 30$, $sd_2 = 6.224$, $p = 0.286$]. It was determined by Levene's test that the distributions of variances were homogeneous (for viewing mediation $F = 1.391$, $p = 0.62$, for laissez-faire mediation $F = 1.127$, $P = 0.63$, for technical mediation $F = 1.645$, $p = 0.45$, for restrictive mediation $F = 1.745$, $p = 0.42$, and active co-playing mediation for $F = 1.120$ $p = 0.66$). When performing the MANOVA analysis, Wilks' lambda values were investigated. In addition, Bonferroni correction was used to check error type 1.

### *23.3.7 Findings*

This section gives the findings related to the research questions. *How long do children play digital games during the COVID 19 pandemic in Greece and Turkey?* The results of the research question are in Table 23.6.

According to Table 23.6, 23.5% of Greek children ($n = 61$) play digital games for 60 min or more on average. 23.8% of Turkish children ($n = 150$) play digital games for 60 min or more on average. 21.5% of Greek children ($n = 56$) play digital games for an average of 0–15 min, and 14.4% of Turkish children ($n = 91$) were found to play digital games for an average of 0–15 min. In this context, it was determined that there is a significant relationship between the random distribution of children's digital gaming time during the pandemic in both countries and their expected values ($X^2 = 18.803$, df $= 4$, $p = 0.001$, $p < 0.05$). In this context, it was determined that approximately 24% of Greek and Turkish children turned to digital games for 60 min or more during the pandemic.

*Children play digital games on which devices during the COVID 19 pandemic in Greece and Turkey?* The findings of the research question are in Table 23.7.

According to Table 23.7, 46.2% of Greek children ($n = 63$) used smartphones/tablets, laptops, and desktop computers together during the pandemic. 58.6% of Turkish children ($n = 369$) only used smartphones/tablets during the pandemic.

**Table 23.6** Average times spent by Greek and Turkish children playing digital games during the pandemic

| Country | | Average time daily minutes | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | 0–15 | 16–30 | 31–45 | 46–60 | 60+ | |
| Greece | Count | 56 | 49 | 43 | 51 | 61 | 260 |
| | Expected count | 42.9 | 51.4 | 63.4 | 40.6 | 61.6 | 260.0 |
| | % within country | 21.5 | 18.8 | 16.5 | 19.6 | 23.5 | 100.0 |
| Turkey | Count | 91 | 127 | 174 | 88 | 150 | 630 |
| | Expected count | 104.1 | 124.6 | 153.6 | 98.4 | 149.4 | 630.0 |
| | % within country | 14.4 | 20.2 | 27.6 | 14.0 | 23.8 | 100.0 |
| Total | Count | 147 | 176 | 217 | 139 | 211 | 890 |
| | Expected count | 147.0 | 176.0 | 217.0 | 139.0 | 211.0 | 890.0 |
| | % within country | 16.5 | 19.8 | 24.4 | 15.6 | 23.7 | 100.0 |

0.8% of Greek children ($n = 2$) only play using a gaming console, while 1.9% of Turkish children ($n = 12$) only play using a gaming console. In this context, it was determined that there is a significant relationship between the random distribution of the technological tools that children use to play during the pandemic in both countries and their expected values ($x^2 = 324.108$, df = 6, $p = 0.000$, $p < 0.05$). While Greek children use various technological tools together, most Turkish children only use smartphones/tablets in this context.

Descriptive statistics values are given in Table 23.8 to examine the mean and standard deviation.

Pairwise comparisons values are given in Table 23.10 to examine the significant difference between the groups.

Table 23.9 shows the situation for Turkey and Greece concerning parents playing digital games with their children during the pandemic in terms of parental mediation strategies. In Table 23.1, when Bonferroni correction was used to check Type I errors for multiple ANOVAs, the significance between groups was 0.017.

*"Is there a significant difference between the mediation strategies scores of Greek and Turkish parents?"* When the findings for this research question are examined, according to the analysis results in Table 23.9 ($\lambda = 0.889$, $F_{(5.882)} = 22.056$, $p = 0.000$, $p < 0.01$), there is a significant difference in parental mediation strategies between countries (see Multivariate Test in Table 23.9). When examining whether or not there is a significant difference in which mediation type, no significant difference is seen in the viewing mediation ($F_{(1.886)} = 0.18$, $p = 0.895$, $p > 0.01$) and active co-playing mediation strategies ($F_{(1.886)} = 0.127$, $p = 0.722$, $p > 0.01$) between Turkish and Greek parents. In the Laissez-faire mediation ($F_{(1.886)} = 71.824$, $p = 0.000$, $p < 0.01$), technical mediation ($F_{(1.886)} = 9.556$, $p = 0.002$, $p < 0.01$), and restrictive mediation ($F_{(1.886)} = 17.707$, $p = 0.000$, $p < 0.01$) strategies, there is a significant difference between Greek and Turkish parents (see Tests of Between-Subjects Effects in Table 23.9). When the direction of the significant difference is examined, it is seen

**Table 23.7** Technological tools used by Greek and Turkish children in the pandemic

| Country | | Technological tools | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Smartphone/tablet | Desktop computer | Laptop | Gaming console | Smartphone/tablet Gaming console | Smartphone/tablet Laptop Desktop computer | Smartphone/tablet Gaming console Laptop Desktop computer | Total |
| Greece | Count | 44 | 7 | 21 | 2 | 9 | 120 | 57 | 260 |
| | Expected count | 120.7 | 23.4 | 30.7 | 7.0 | 6.1 | 53.5 | 18.7 | 260.0 |
| | % within country | 16.9 | 2.7 | 8.1 | 0.8 | 3.5 | 46.2 | 21.9 | 100.0 |
| Turkey | Count | 369 | 73 | 84 | 12 | 22 | 63 | 7 | 630 |
| | Expected count | 292.3 | 56.6 | 74.3 | 14.9 | 17 | 129.5 | 45.3 | 630.0 |
| | % within country | 58.6 | 11.6 | 13.3 | 1.9 | 3.5 | 10.0 | 1.1 | 100.0 |
| Total | Count | 413 | 80 | 105 | 24 | 21 | 183 | 64 | 890 |
| | Expected count | 413.0 | 80.0 | 105.0 | 24.0 | 21.0 | 183.0 | 64.0 | 890.0 |
| | % within country | 46.4 | 9.0 | 11.8 | 2.7 | 2.4 | 20.6 | 7.2 | 100.0 |

**Table 23.8** Descriptive statistics

| | Country | *Q** | *N* | Mean | SD |
|---|---|---|---|---|---|
| Viewing | Greece | Yes | 176 | 56.10 | 7.22 |
| | | No | 84 | 55.73 | 9.28 |
| | | Total | 260 | 55.98 | 7.933 |
| | Turkey | Yes | 412 | 59.71 | 6.81 |
| | | No | 218 | 51.96 | 9.05 |
| | | Total | 630 | 57.03 | 8.50 |
| | Total | Yes | 588 | 58.63 | 7.12 |
| | | No | 302 | 53.01 | 9.26 |
| | | Total | 890 | 56.72 | 8.34 |
| Laissez-faire | Greece | Yes | 176 | 21.78 | 6.06 |
| | | No | 84 | 19.72 | 5.79 |
| | | Total | 260 | 21.12 | 6.04 |
| | Turkey | Yes | 412 | 26.12 | 13.00 |
| | | No | 218 | 29.17 | 8.73 |
| | | Total | 630 | 27.17 | 11.78 |
| | Total | Yes | 588 | 24.82 | 11.54 |
| | | No | 302 | 26.54 | 9.06 |
| | | Total | 890 | 25.41 | 10.79 |
| Technical | Greece | Yes | 176 | 11.78 | 4.89 |
| | | No | 84 | 12.23 | 5.11 |
| | | Total | 260 | 11.93 | 4.96 |
| | Turkey | Yes | 412 | 14.93 | 4.69 |
| | | No | 218 | 11.40 | 4.67 |
| | | Total | 630 | 13.71 | 4.97 |
| | Total | Yes | 588 | 13.98 | 4.96 |
| | | No | 302 | 11.63 | 4.80 |
| | | Total | 890 | 13.19 | 5.03 |
| Restrictive | Greece | Yes | 176 | 39.12 | 5.35 |
| | | No | 84 | 38.86 | 6.22 |
| | | Total | 260 | 39.04 | 5.64 |
| | Turkey | Yes | 412 | 40.08 | 5.26 |
| | | No | 218 | 34.02 | 7.10 |
| | | Total | 630 | 37.99 | 6.62 |
| | Total | Yes | 588 | 39.79 | 5.30 |
| | | No | 302 | 35.37 | 7.19 |
| | | Total | 890 | 38.29 | 6.36 |

(continued)

**Table 23.8** (continued)

| | Country | *Q** | *N* | Mean | SD |
|---|---|---|---|---|---|
| Active co-playing | Greece | Yes | 176 | 16.53 | 3.49 |
| | | No | 84 | 14.78 | 5.04 |
| | | Total | 260 | 15.96 | 4.13 |
| | Turkey | Yes | 412 | 17.89 | 3.21 |
| | | No | 218 | 13.62 | 3.95 |
| | | Total | 630 | 16.41 | 4.03 |
| | Total | Yes | 588 | 17.48 | 3.35 |
| | | No | 302 | 13.95 | 4.30 |
| | | Total | 890 | 16.28 | 4.06 |

Q* = do you play digital games with your child during the pandemic

that the Greek and Turkish parents' laissez-faire mediation strategy is also in favor of Greek parents ($p = 0.000$). Since it is among the mediation strategies but does not show the characteristics of a mediation strategy, the low arithmetic means in laissez-faire mediation is in favor of the parents. In laissez-faire mediation, the higher the arithmetic mean, the higher the level of parental negligence in mediation. When the direction of the significant difference in technical and restrictive mediation strategies is examined, it favors Turkish parents in the technical mediation strategy and Greek parents in the restrictive mediation strategy ($p = 0.000$) (cf. Pairwise Comparisons in Table 23.10).

The country variable's effect size (partial eta squared) explaining the variance on parental mediation strategies was examined. According to Cohen (1992), the level of 0.01 is small, 0.06 is medium, and 0.14 is interpreted as a large effect. In this context, laissez-faire mediation ($\eta_p^2 = 0.075$) can be interpreted as a medium effect, technical ($\eta_p^2 = 0.011$), and restrictive ($\eta_p^2 = 0.020$). In contrast, mediation strategies can be interpreted as small effects.

*Is there a significant difference between the mediation strategies used by parents who play and do not play digital games with their children during the pandemic?* When the findings for this research question are examined, according to the analysis results in Table 23.9 ($\lambda = 0.880$, $F_{(5.882)} = 23.869$, $p = 0.000$, $p < 0.01$), there is a significant difference between the mediation strategies used by parents who play and do not play digital games with their children (see Multivariate Test in Table 23.9). When examining whether there is a significant difference in which mediation type, there is no significant difference between playing and not playing digital games with their children during the pandemic period in the laissez-faire mediation ($F_{(1.886)} = 0.358$, $p = 0.544$, $p > 0.01$) strategy. A significant difference was found between the viewing mediation ($F_{(1.886)} = 44.613$, $p = 0.000$, $p < 0.01$), technical mediation ($F_{(1.886)} = 16.892$, $p = 0.000$, $p < 0.01$), restrictive mediation ($F_{(1.886)} = 46.940$, $p = 0.000$, $p < 0.01$) and active co-playing mediation ($F_{(1.886)} = 109.728$, $p = 0.000$, $p < 0.01$) strategies (see Tests of Between-Subjects Effects in Table8). When the

**Table 23.9** Multidirectional analysis of variance values

| Multivariate test | | | | | | | |
|---|---|---|---|---|---|---|---|
| Effect | | λ | *F* | Hypothesis df | Error df | Sig | $\eta_p^2$ |
| Intercept | | 0.018 | 9409.133[b] | 5.00 | 882.00 | 0.000 | 0.982 |
| Country | | 0.889 | 22.056[b] | 5.00 | 882.00 | 0.000 | 0.111 |
| Digital game (dg) | | 0.881 | 23.869[b] | 5.00 | 882.00 | 0.000 | 0.119 |
| Country * dg | | 0.923 | 14.622[b] | 5.00 | 882.00 | 0.000 | 0.077 |
| Tests of between-subjects effects | | | | | | | |
| Corrected model | Dependent variable | Sum of squares | df | Mean square | *F* | Sig | $\eta_p^2$ |
| | Viewing | 8778.775[a] | 3 | 2926.258 | 48.747 | 0.000 | 0.142 |
| | Laissez-faire | 8319.322[b] | 3 | 2773.107 | 25.796 | 0.000 | 0.080 |
| | Technical | 2369.920[c] | 3 | 789.973 | 34.733 | 0.000 | 0.105 |
| | Restrictive | 5442.597[d] | 3 | 1814.199 | 52.519 | 0.000 | 0.151 |
| | Active co-playing | 2807.010[e] | 3 | 935.670 | 69.797 | 0.000 | 0.191 |
| Intercept | Viewing | 2,030,861.075 | 1 | 2,030,861.075 | 33,831.216 | 0.000 | 0.974 |
| | Laissez-faire | 381,000.479 | 1 | 381,000.479 | 3544.154 | 0.000 | 0.800 |
| | Technical | 103,082.222 | 1 | 103,082.222 | 4532.187 | 0.000 | 0.836 |
| | Restrictive | 940,498.646 | 1 | 940,498.646 | 27,226.539 | 0.000 | 0.968 |
| | Active co-playing | 160,536.791 | 1 | 160,536.791 | 11,975.360 | 0.000 | 0.931 |
| Country | Viewing | 1.054 | 1 | 1.054 | 0.018 | 0.895 | 0.000 |
| | Laissez-faire | 7721.144 | 1 | 7721.144 | 71.824 | 0.000 | 0.075 |
| | Technical | 217.569 | 1 | 217.569 | 9.566 | 0.002 | 0.011 |
| | Restrictive | 611.675 | 1 | 611.675 | 17.707 | 0.000 | 0.020 |
| | Active co-playing | 1.696 | 1 | 1.696 | 0.127 | 0.722 | 0.000 |
| Pandemic digital game | Viewing | 2678.110 | 1 | 2678.110 | 44.613 | 0.000 | 0.048 |
| | Laissez-faire | 39.594 | 1 | 39.594 | 0.368 | 0.544 | 0.000 |
| | Technical | 384.202 | 1 | 384.202 | 16.892 | 0.000 | 0.019 |
| | Restrictive | 1621.461 | 1 | 1621.461 | 46.940 | 0.000 | 0.050 |
| | Active co-playing | 1470.963 | 1 | 1470.963 | 109.728 | 0.000 | 0.110 |
| Country * pandemic digital game | Viewing | 2219.043 | 1 | 2219.043 | 36.966 | 0.000 | 0.040 |
| | Laissez-faire | 1063.135 | 1 | 1063.135 | 9.890 | 0.002 | 0.011 |
| | Technical | 644.663 | 1 | 644.663 | 28.344 | 0.000 | 0.031 |
| | Restrictive | 1369.270 | 1 | 1369.270 | 39.639 | 0.000 | 0.043 |
| | Active co-playing | 257.894 | 1 | 257.894 | 19.238 | 0.000 | 0.021 |

(continued)

**Table 23.9** (continued)

| Multivariate test | | | | | | | |
|---|---|---|---|---|---|---|---|
| Effect | | λ | *F* | Hypothesis df | Error df | Sig | $\eta_p^2$ |
| Error | Viewing | 53,185.878 | 886 | 60.029 | | | |
| | Laissez-faire | 95,245.987 | 886 | 107.501 | | | |
| | Technical | 20,151.608 | 886 | 22.744 | | | |
| | Restrictive | 30,605.499 | 886 | 34.543 | | | |
| | Active co-playing | 11,877.354 | 886 | 13.406 | | | |
| Total | Viewing | 2,925,939.000 | 890 | | | | |
| | Laissez-faire | 678,215.000 | 890 | | | | |
| | Technical | 177,384.000 | 890 | | | | |
| | Restrictive | 1,341,427.000 | 890 | | | | |
| | Active co-playing | 250,790.000 | 890 | | | | |
| Corrected total | Viewing | 61,964.653 | 889 | | | | |
| | Laissez-faire | 103,565.309 | 889 | | | | |
| | Technical | 22,521.528 | 889 | | | | |
| | Restrictive | 36,048.096 | 889 | | | | |
| | Active co-playing | 14,684.364 | 889 | | | | |

direction of the significant difference is examined, it is found to favor the parents in the viewing mediation ($p < 0.01$), technical mediation ($p < 0.01$), restrictive mediation ($p < 0.01$), and active co-playing mediation ($p < 0.01$) strategies of parents who play digital games with their children (see Pairwise Comparisons in Table 23.10).

When the effect size of mediation strategies used by parents who play and do not play digital games with their children during the pandemic period is examined, the effect of viewing mediation ($\eta_p^2 = 0.048$) is low to medium, technical ($\eta_p^2 = 0.019$), and restrictive ($\eta_p^2 = 0.050$), while mediation strategies can be interpreted as small to medium effect. Active co-playing mediation strategy ($\eta_p^2 = 0.110$) can be interpreted as large effect (Cohen, 1992).

*Does the mediation strategy used by parents who do not play digital games with their children during the pandemic process differ significantly by country variable?* When the findings for this research question are examined, according to the analysis results in Table 23.9 ($\lambda = 0.923$, $F_{(5.882)} = 14.622$, $p = 0.000$, $p < 0.01$), there is a significant difference between the mediation strategies used by parents who play and do not play digital games with their children (see Multivariate Test in Table 23.9). A significant difference was found between the viewing mediation ($F_{(1.886)} = 36.966$, $p = 0.000$, $p < 0.01$), laissez-faire mediation ($F_{(1.886)} = 9.890$, $p = 0.002$, $p < 0.01$), technical mediation ($F_{(1.886)} = 28.344$, $p = 0.000$, $p < 0.01$), restrictive mediation ($F_{(1.886)} = 39.639$, $p = 0.000$, $p < 0.01$) and active co-playing mediation ($F_{(1.886)}$

**Table 23.10** Pairwise comparisons

| Dependent variable | (*I*) Country | (*J*) Country | Mean difference ($I-J$) | Std. Error | Sig.[b] | (I) Do you play digital games with your child during the pandemic? | (J) Do you play digital games with your child during the pandemic? | Mean difference ($I-J$) | Std. error | Sig.[b] |
|---|---|---|---|---|---|---|---|---|---|---|
| Viewing | Greece | Turkey | 0.081 | 0.608 | 0.895 | Yes | No | 4.058* | 0.608 | 0.000 |
| | Turkey | Greece | −0.081 | 0.608 | 0.895 | No | Yes | −4.058* | 0.608 | 0.000 |
| Laissez-faire | Greece | Turkey | 6.891* | 0.813 | 0.000 | Yes | No | 0.493 | 0.813 | 0.544 |
| | Turkey | Greece | −6.891* | 0.813 | 0.000 | No | Yes | −0.493 | 0.813 | 0.544 |
| Technical | Greece | Turkey | −1.157* | 0.374 | 0.002 | Yes | No | 1.537* | 0.374 | 0.000 |
| | Turkey | Greece | 1.157* | 0.374 | 0.002 | No | Yes | −1.537* | 0.374 | 0.000 |
| Restrictive | Greece | Turkey | 1.940* | 0.461 | 0.000 | Yes | No | 3.158* | 0.461 | 0.000 |
| | Turkey | Greece | −1.940* | 0.461 | 0.000 | No | Yes | −3.158* | 0.461 | 0.000 |
| Active co-playing | Greece | Turkey | −0.102 | 0.287 | 0.722 | Yes | No | 3.008* | 0.287 | 0.000 |
| | Turkey | Greece | 0.102 | 0.287 | 0.722 | No | Yes | −3.008* | 0.287 | 0.000 |

= 19.238, $p = 0.000$, $p < 0.01$) strategies (see Tests of Between-Subjects Effects in Table 23.10).

When the effect size of the mediation strategy used by parents who play or do not play digital games with their children during the pandemic process is examined according to the country variable, the effect size of viewing mediation ($\eta_p^2 = 0.040$) is small to medium. Laissez-faire mediation ($\eta_p^2 = 0.011$) small effect, Technical ($\eta_p^2 = 0.031$), and restrictive ($\eta_p^2 = 0.043$) mediation strategies can be interpreted as small to medium effect. In contrast, active co-playing mediation strategy ($\eta_p^2 = 0.021$) can be interpreted as low to medium effect size. (Cohen, 1992).

How the parents affect the mediation variables was examined, considering the estimates marginal means values looking at whether or not parents played digital games with their children and by country. It was also reviewed whether parents who played digital games with their children or not made a significant difference in Turkey and Greece. In this regard, the viewing mediation strategy in Fig. 23.2 was examined.

According to Fig. 23.2, there is no significant difference in viewing mediation strategies according to whether or not Greek parents played digital games with their children during the pandemic [$t_{258} = 0.346$; $p = 0.730$, $p > 0.01$]. There is a significant difference in the viewing mediation strategy according to whether or not Turkish parents played digital games with their children during the pandemic. [$t_{628} = 12.078$; $p = 0.000$, $p < 0.01$]. When Fig. 23.1 is examined, Turkish parents playing digital games with their children significantly differed in the viewing mediation strategy. It can be said that the effect size of this difference detected in Turkish parents is Eta squared ($\eta^2 = 0.18$), and according to Cohen (1992), the difference has a large effect.

According to Fig. 23.3, there is no significant difference in the laissez-faire mediation strategy regarding whether Greek parents played digital games with their children during the pandemic [$t_{258} = 2.603$; $p = 0.015$, $p < 0.01$]. There is a significant

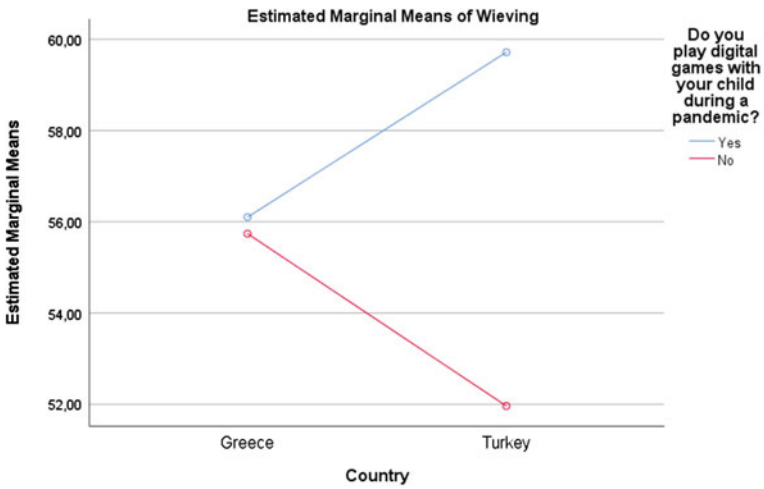



**Fig. 23.2** Profile plot of Greek and Turkish parents' viewing mediation strategy

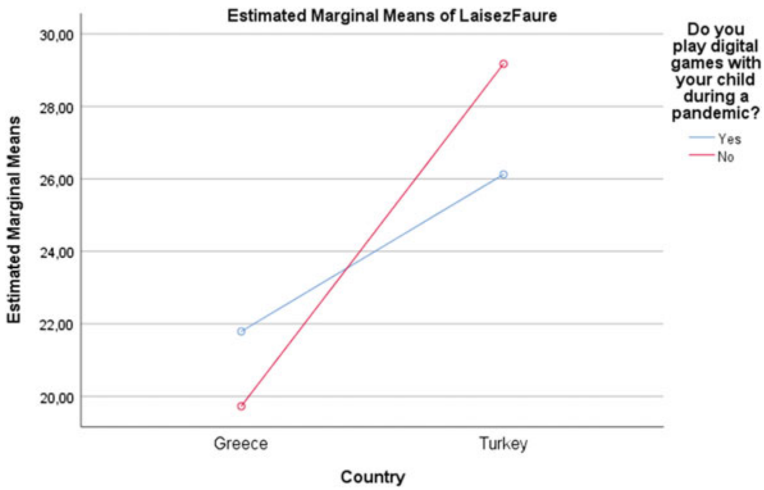



**Fig. 23.3** Profile plot for Greek and Turkish parents' use of the laissez-faire mediation strategy

difference in the laissez-faire mediation strategy according to whether or not Turkish parents played digital games with their children during the pandemic [$t_{628} = 3.112$; $p = 0.002$; $p < 0.01$]. When Fig. 23.2 is examined, it can be seen that Turkish parents who played and those who did not play digital games with their children during the pandemic scored higher than their Greek counterparts in the use of the laissez-faire mediation strategy. It can be said that the effect size of this difference detected in Turkish parents is Eta squared ($\eta^2 = 0.01$), and according to Cohen (1992), the difference has a negligible effect.

According to Fig. 23.4, there is no significant difference in the technical mediation strategy according to whether or not Greek parents played digital games with their children during the pandemic [$t_{258} = 0.689$; $p = 0.491$; $p > 0.01$] There is a significant difference in the technical mediation strategy according to whether or not Turkish parents played digital games with their children during the pandemic [$t_{628} = 8.993$; $p = 0.000$, $p < 0.01$]. When Fig. 23.3 is examined, it is seen that Turkish parents playing digital games with their children during the pandemic made a significant difference in using the technical mediation strategy. It was determined that the effect size of this difference detected in Turkish parents was Eta squared ($\eta^2 = 0.11$) and explained 11% of the total variance. According to Cohen (1992), it can be said that the difference is above the medium effect.

According to Fig. 23.5, there is no significant difference in the restrictive mediation strategy according to whether or not Greek parents played digital games with their children during the pandemic [$t_{258} = 0.341$; $p = 0.733$; $p > 0.01$]. There is a significant difference in the restrictive mediation strategy according to whether or not Turkish parents played digital games with their children during the pandemic. [$t_{628} = 12.125$; $p = 0.000$, $p < 0.01$]. When Fig. 23.4 is examined, it is seen that Turkish parents playing digital games with their children during the pandemic made a significant

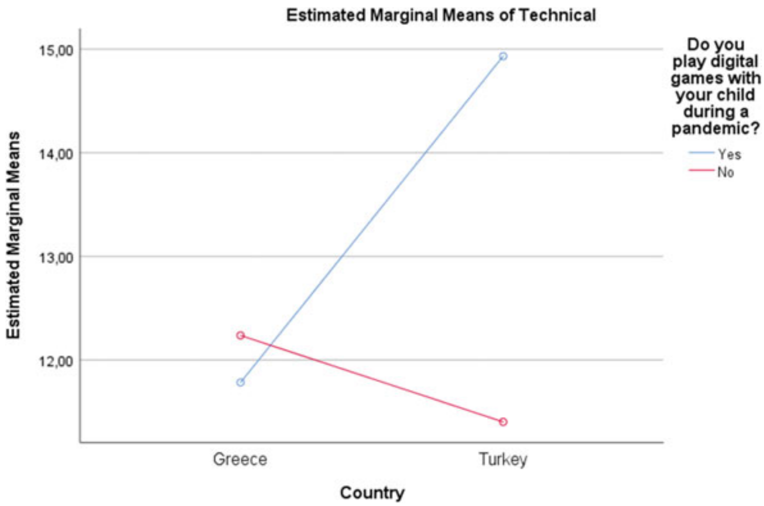



**Fig. 23.4** Profile plot for Greek and Turkish parents use of the technical mediation strategy

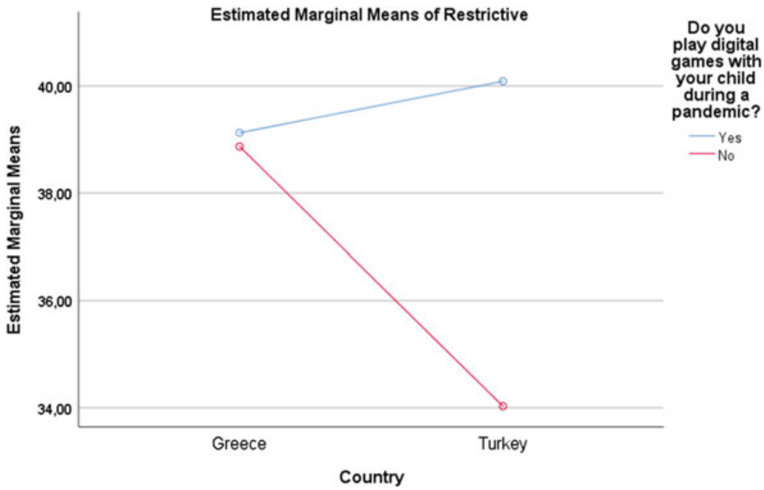



**Fig. 23.5** Profile plot for Greek and Turkish parents use of the restrictive mediation strategy

difference in using the restrictive mediation strategy. It was determined that the effect size of this difference detected in Turkish parents was Eta squared ($\eta^2 = 0.18$), explaining 18% of the total variance. According to Cohen (1992), it can be said that the difference has a large effect.

According to Fig. 23.6, there is a significant difference in the active co-playing mediation strategy according to the situation of Greek parents playing and not playing digital games with their children during the pandemic [$t_{258} = 3.248$; $p = 0.001$; $p$

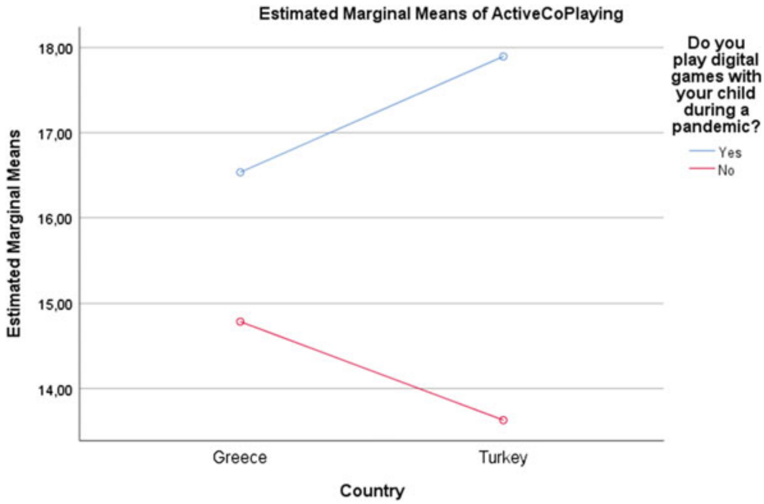



**Fig. 23.6** Profile plot for Greek and Turkish parents use of the active co-playing mediation strategy

$< 0.05$]. It was determined that the effect size of this difference detected in Greek parents was Eta squared ($\eta^2 = 0.03$), explaining 3% of the total variance. According to Cohen (1992), it can be said that the difference has an effect between small and medium effects. There is a significant difference in the active co-playing strategy according to Turkish parents playing or not playing digital games with their children during the pandemic [$t_{628} = 14.620$; $p = 0.000$, $p < 0.05$]. It was determined that the effect size of this difference detected in Turkish parents was Eta squared ($\eta^2 = 0.25$), explaining 25% of the total variance. According to Cohen (1992), it can be said that the difference has a large effect. When Fig. 23.5 is examined, it is seen that Greek and Turkish parents playing digital games with their children during the pandemic made a significant difference in using the active co-playing mediation strategy.

## 23.4 Conclusion and Discussion

The study aims to compare the mediation strategies of Greek and Turkish parents for the digital games played by their children. The technological tools used by children and the time they play digital games during the pandemic were examined. Today, children can use specialized devices such as computers, tablets, game consoles, and smartphones when playing digital games (Bailey, West, & Anderson, 2011; Eyimaya et al., 2020). When the digital tools used by children during the pandemic process were examined, it was seen that 46% of Greek children use smartphones/tablets, laptops, and desktop computers together and that 58.6% of Turkish children only use smartphones/tablets. With the use of the touch screen, the children have become independent in playing digital games. This may increase children's exposure to online risks (Gözüm & Kandır, 2021; Papadakis & Kalogiannakis, 2017). Parents should use mediation strategies for the children and keep the time they play digital games under control so that the children do not experience such problems as online risks (Hasebrink et al., 2011; Livingstone & Helsper, 2008; Nikken & Jansz, 2014), attention or (Gentile et al., 2012) sleep disorders (Foti et al., 2011; King et al., 2013) or obesity (Fullerton et al., 2014). However, considering the pandemic conditions, it is inevitable that children will use technological devices when staying at home. In this regard, when the time spent by children playing digital games under pandemic conditions was examined, it was determined that 24% of Greek and Turkish children spend an average of 60 min or more playing digital games. Accordingly, it can be said that the time spent by children in front of the screen during the pandemic is similar. However, the critical factor that makes the time spent by children playing digital games meaningful is the mediation strategy that their parents apply to their children at this time. Parental mediation strategies used for digital games during the pandemic in Greece and Turkey were discussed in light of the literature. An attempt was made to understand how the pandemic affected mediation strategies in the two countries.

Parents can use different mediation strategies together (Blum-Ross & Livingstone, 2016, p. 11). This means that when Greek and Turkish parents use active co-playing mediation strategies, they can use restricted mediation strategies simultaneously. When the significant difference between the parental mediation strategies used by Greek and Turkish parents for their children was examined, no significant difference was found between the viewing and co-playing mediation strategies used by Greek and Turkish parents. Significant differences were found in laissez-faire, technical, and restricted mediation strategies. Piotrowski (2017) said that in the case of early childhood children, parents use active and restrictive mediation strategies to protect children from online risks and make positive use of technology. While there is no significant difference in the active co-play strategy between Greek and Turkish parents, a significant difference was found between technical and restrictive mediation is an effective result. Technical mediation differs in favor of Turkish parents, while restricted mediation differs from Greek parents.

In their report, Helsper et al. (2013) compared the mediation strategies of parents in Turkey and European countries, opportunities, risks, and harm using cluster analysis. The report concludes that Turkey (15%) and Greece (19%) are below the average of European countries (31%) in using the active mediation strategy. Similar to the results of that report, this study determined that there was no significant difference between Greek and Turkish parents' active co-play mediation. Furthermore, Helsper et al. (2013) reported that Greek and Turkish children are low-risk for online risks. Greece (29%) and Turkey (38%) are above the European average (24%) in restrictive mediation strategy. In this study, restricted mediation favors Greek parents, while technical mediation favors Turkish parents. Both restrictive and technical mediation protect children from online risks. In this context, the study's results are consistent with the research report prepared by Helsper et al. (2013). Based on this, the reason why Greek and Turkish parents differ in their use of restrictive mediation and technical mediation for digital games can be discussed. Kirwil (2009), who studied parental mediation of internet use in European countries, found that parents in European cultures use the internet socially together with their children instead of installing software and filters on the technological tools they use and that they use restrictive mediation by setting rules for their children's online risks. In this context, according to the study's findings, Greek parents, whom the significant difference in restrictive mediation favors, use restrictive mediation based on social interaction when playing digital games with their children.

On the other hand, Turkish parents use a technical mediation strategy not based on social interaction with their children. This means that, in line with the study made by Kirwil (2009) in Europe, there is a significant difference in the use of restrictive mediation by Greek parents compared with Turkish parents. In addition, studies in the United States (Barkin et al., 2006; Turow & Nir, 2000) have yielded results similar to the effects of restrictive parental mediation use in Europe. This shows differences between Greek and Turkish parents in preferring social mediation for their children. Let us consider parental mediation as a communication strategy. The fact that between Turkish and Greek parents, the laissez-faire strategy (not actually mediation) favors Turkish parents in the study suggests that the purpose of mediation for digital games has disappeared. In their study of Turkish parents, Gözüm and Kandır (2021)) found that the majority of parents could not use a deliberate mediation strategy. The emergence in this study of a negligent mediation strategy and an active co-playing approach is consistent with the study results made by Gözüm and Kandır (2021).

Bayraktar (2017) study examined Turkish children's online risks in Turkey and Europe and parental mediation strategies. A model was proposed in which viewing mediation is the mediating variable in the viewing, active co-playing, and restrictive mediation roles used by Turkish parents in Turkey and Europe for online risks. The study concluded that parents in Turkey use the viewing mediation strategy in their children's Internet use. In contrast, Turkish parents in Europe use viewing mediation as an extension of the restrictive mediation strategy, which means that parents can use the viewing strategy as a mediating variable.

In contrast, use the viewing strategy, active co-playing, and restrictive mediation strategies for online risks. It can be thought that the absence of a significant difference in the viewing mediation strategies of Greek and Turkish parents may be due to the mediating role of active and restrictive mediation in online risks. If Turkish and Greek parents ultimately use the active co-play, restrictive, and viewing mediation strategies, viewing mediation can be used in conjunction with the other two mediation types for digital games.

When the mediation strategies of parents who played and did not play digital games with their children during the pandemic were examined, a significant difference was found between the viewing, restrictive, technical, and active co-play mediation strategies. The significant difference in all mediation strategies favors parents who play digital games with their children. This means that parents who interact with their children through communication and digital games deliberately use mediation strategies. No significant difference was found in laissez-faire mediation for parents who play and do not play digital games with their children during the pandemic.

This may result from the paradox mentioned in the Introduction section for the time spent with digital games that generate a feeling of normalcy by meeting children's learning and entertainment needs during the pandemic. Ultimately, when parents use the active co-play strategy with their children, they may neglect the time spent in front of the screen.

When examining whether the mediation strategies of parents who play and do not play digital games with their children during the pandemic differ significantly by country, significant differences were found in the viewing, laissez-fair, technical, restrictive, and active mediation strategies of Greece and Turkey. When the situation regarding playing digital games or not with their children during the pandemic process is examined in the two countries, no significant difference is seen in Greek parents' use of viewing, laissez-faire, technical, and restrictive mediation strategies. Still, a significant difference is seen in the active co-play strategy. Significant differences were found in the viewing, laissez-faire, technical, restrictive, and active mediation strategies among Turkish parents who play digital games with their children and those who do not. While this situation does not affect the Greek parents much in the case of parents playing digital games or not during the pandemic, it can be said that it affects Turkish parents positively. Helsper et al. (2013) reported that Turkish and Greek parents, who are close neighbors, are among those groups that exhibit the most restrictive parenting strategies throughout Europe. The strong relationship between Turkish parents' active and restrictive strategies indicates that parents living in Turkey use both approaches. According to Bayraktar (2017), when viewed from this perspective, in Turkey, parents' use of other mediation strategies improves as they develop active mediation strategies depending on the online risks faced by their children. This situation is consistent with significant differences in parental mediation strategies resulting from Turkish parents playing digital games with their children during the pandemic. While viewing, technical, and restrictive mediation can be used for early childhood children's inability to distinguish harmful situations and their vulnerability to digital content, active co-play mediation can be exhibited for the positive aspects of technology. While the results of this study are similar to the results of the study made by Nikken and Jansz (2014), the pandemic increased the awareness of both Turkish and Greek parents about active co-play. The active-co-playing strategy by Turkish and Greek parents may indicate the necessity of both parents and children to stay at home during the pandemic. However, this is extremely important in parents discovering their children's games and directing them to educational digital games that can be positive for their children.

According to the results of the research conducted by Gözüm and Kandır (2021), parents consciously use the active co-playing mediation strategy to support their children's education. In the same research results, parents who deliberately use the active co-playing approach in Turkey constitute a low part of the study group, such as 9%. Parents using the active-co playing strategy also emphasized that they received expert opinions. In the results of the research conducted in Greece by Papadakis et al. (2021), it was determined that the mobile applications that Greek parents want to use for their children do not have enough information about the development level of the children and that expert support is needed about the educational content of the mobile applications. Research results on Turkish (Gözüm & Kandır, 2021) and Greek (Papadakis et al., 2021) parents show that parents should get expert support in addition to parental mediation, which they use consciously to support their children's educational aspects with digital games. Parents perceive mobile applications as an essential support to the school process to support their children's educational goals during the pandemic (Archer et al., 2021; Levinthal et al., 2021). In this study, when the duration of children's use of the digital tools they play is examined, it may be that both Turkish and Greek parents prefer mobile applications for their children in addition to their school goals so that children can spend adequate time.

## 23.5 Recommendations

Parents in Greece and Turkey can use more than one mediation strategy together. However, being above the European average in restricted mediation, both Greek and Turkish parents protect their children from online risks in digital games. However, the active co-mediation strategy is expected to be used deliberately to benefit positively from digital games. Greek and Turkish parents must not use the laissez-faire mediation strategy. This means that training on parental mediation strategies can be given to Greek and Turkish parents together by using the advantage of being in neighboring countries. In addition, large-scale surveys can be planned to explore the parental mediation profiles of Greece and Turkey. In response to the adversities introduced by the pandemic, model studies can be done for parents to have the opportunity to play digital games with their children and use a deliberate parental mediation strategy after the pandemic.

## 23.6 Limitations

The results of this study are limited to the parents in the working group. An important limitation of the study is the number of parents in Greece and Turkey, limiting the potential to represent Greek and Turkish parents. However, despite these limitations, it has crucial results in determining the mediation strategies used by parents during the pandemic and comparing different countries. Despite the limits of the research, it is thought that the results will contribute not only to the relevant literature but also to the applied fields that focus on the interactions of parents and children in digital games.

## References

Abbott, M. L. (2011). *Understanding educational statistics using Microsoft Excel and SPSS*. Wiley.

American Academy of Pediatrics. (2013). Children, adolescents, and the media. *Pediatrics, 132*(5), 958–961.
Archer, K., Wood, E., & De Pasquale, D. (2021). Examining joint parent–child interactions involving infants and toddlers when introducing mobile technology. *Infant Behavior and Development, 63*, 101568.
Atkin, D. J., Greenberg, B. S., & Baldwin, T. F. (2006). The home ecology of children's television viewing: Parental mediation and the new video environment. *Journal of Communication, 41*, 40–52.
Bailey, K., West, R., & Anderson, C. A. (2011). The influence of video games on social, cognitive, and affective information processing. *Handbook of social neuroscience* (pp. 1001–1011).
Barkin, S., Ip, E., Richardson, I., Klinepeter, S., & Krcmar, M. (2006). Parental mediation styles for children aged 2–11 years. *Archives of Pediatrics and Adolescent Medicine, 160*, 395–401.
Bayraktar, F. (2017). Çevrimiçi riskler ve ebeveyn aracılık stratejileri: Türkiye'de ve Avrupa'da yaşayan türk kökenli çocuk/ergenlerin karşılaştırılması. *Eğitim ve Bilim*, *42*(190).
Beyens, I., Valkenburg, P. M., & Piotrowski, J. T. (2019). Developmental trajectories of parental mediation across early and middle childhood. *Human Communication Research, 45*(2), 226–250. https://doi.org/10.1080/00405840802153940
Blackwell, C. K., Lauricella, A. R., & Wartella, E. (2016). The influence of TPACK contextual factors on early childhood educators' tablet computer use. *Computers & Education, 98*, 57–69.
Bluemke, M., Friedrich, M., & Zumbach, J. (2010). The influence of violent and nonviolent computer games on implicit measures of aggressiveness. *Aggressive Behavior, 36*(1), 1–13. https://doi.org/10.1002/ab.20329
Blum-Ross, A., & Livingstone, S. (2016). Families and screen time: Current advice and emerging research. Media policy brief 17. Media Policy Project, London School of Economics and Political Science.
Bolstad, R. (2004). *The role and potential of ICT in early childhood education: A review of New Zealand and international literature*. Ministry of Education.
Büyüköztürk, Ş., Kılıç Çakmak, E., Akgün, Ö. E., Karadeniz, Ş., & Demirel, F. (2012). *Bilimsel araştırma yöntemleri.* Pegem.
Cattell, R.B. (1978). *The scientific use of factor analysis in behavioral and life sciences*. New York, NY: Plenum Press.
Clark, L. S. (2011). Parental mediation theory for the digital age. *Communication Theory, 21*(4), 323–343. https://doi.org/10.1111/j.1468-2885.2011.01391.x
Clements, D. H., & Sarama, J. (2007). Effects of a preschool mathematics curriculum: Summative research on the building blocks project. *Journal for Research in Mathematics Education, 38*(2), 136–163. https://doi.org/10.2307/3003495
Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155.
Dias, M. J. A., Almodóvar, M., Atiles, J. T., Vargas, A. C., & Zúñiga León, I. M. (2020). Rising to the challenge: Innovative early childhood teachers adapt to the COVID-19 era. *Childhood Education, 96*(6), 38–45. https://doi.org/10.1080/00094056.2020.1846385
Eyimaya, A. Ö., Uğur, S., Sezer, T. A., & Tezel, A. (2020). İlkokul Dördüncü Sınıf Öğrencilerinde Dijital Oyun Bağımlılığının Uyku ve Diğer Bazı Değişkenlere Göre İncelenmesi. *Journal of Turkish Sleep Medicine, 2*, 83–90.
Foti, K. E., Eaton, D. K., Lowry, R., & McKnight-Ely, L. R. (2011). Sufficient sleep, physical activity, and sedentary behaviors. *American Journal of Preventive Medicine, 41*(6), 596–602.
Fullerton, S., Taylor, A. W., Dal Grande, E., & Berry, N. (2014). Measuring physical inactivity: do current measures provide an accurate view of "sedentary" video game time. *Journal of obesity.* 3, 1–5. https://dx.doi.org/10.1155/2014/287013
Gentile, D. A., Swing, E. L., Lim, C. G., & Khoo, A. (2012). Video game playing, attention problems, and impulsiveness: Evidence of bidirectional causality. *Psychology of Popular Media Culture, 1*(1), 62–70.
Gnanadesikan, R. (1997). *Methods for statistical data analysis of multivariate observations* (2nd ed.). Wiley.

Gözüm, A. İC., & Kandır, A. (2020b). Developing a parental mediation scale of digital games for children. *International Journal of Curriculum and Instruction, 12*(2), 336–358.
Gözüm, A. İC., & Kandır, A. (2021). Digital games preschoolers play: Parental mediation and examination of educational content. *Education and Information Technologies, 26*(3), 3293–3326.
Gözüm, A. İ. C., & Kandır, A. (2020a). Okul öncesi çocukların dijital oyun oynama sürelerine göre oyun eğilimi ile konsantrasyon düzeylerinin incelenmesi. *Atatürk Üniversitesi Kazım Karabekir Eğitim Fakültesi Dergisi* (41), 82–100. https://doi.org/10.33418/ataunikkefd.777424
Guernsey, L., Levine, M., Chiong, C., & Severns, M. (2012). *Pioneering literacy in the digital wild west: Empowering parents and educators.* Campaign for Grade-Level Reading.
Gürbüz, S. (2019). *Sosyal bilimlerde aracı, düzenleyici ve durumsal etki analizleri.* Seçkin Yayıncılık.
Hair Jr., J. F., Anderson, R. E., Tatham, R. L., William, C., & Black. (1995). *Multivariate data analysis with readings.* Prentice-Hall.
Hasebrink, U., Görzig, A., Haddon, L., Kalmus, V., & Livingstone, S. (2011). *Patterns of risk and safety online: in-depth analyses from the EU Kids Online survey of 9- to 16-year-olds and their parents in 25 European countries.* London School of Economics and Political Science.
Hatzigianni, M., & Margetts, K. (2012). 'I am very good at computers': Young children's computer use and their computer self-esteem. *European Early Childhood Education Research Journal, 20*(1), 3–20.
Helsper, E. J., Kalmus, V., Hasebrink, U., Sagvari, B., & De Haan, J. (2013). *Country classification: Opportunities, risks, harm and parental mediation.* LSE, EU Kids Online.
Hooper, D., Coughlan, J., & Mullen, M. R. (2008). Structural equation modeling: Guidelines for determining model fit. *The Electronic Journal of Business Research Methods, 6*, 53–60. https://doi.org/10.21427/D7CF7R
Hu, L.-T., & Bentler, P. M. (1998). Fit indices in covariance structure modeling: Sensitivity to under parameterized model misspecification. *Psychological Methods, 3*(4), 424–453. https://doi.org/10.1037/1082-989X.3.4.424
Jack, C., & Higgins, S. (2019). Embedding educational technologies in early years education. *Research in Learning Technology*, *27*.
Jöreskog, K. G., & Sörbom, D. (1984). *Lisrel VI. Analysis of linear structural relationships by maximum likelihood, instrumental variables, and least-squares methods.* Scientific Software.
Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), 31–36. https://doi.org/10.1007/BF02291575
Kalaycı, Ş. (2008). *SPSS uygulamalı çok değişkenli istatistik teknik.* Asil.
Karasar, N. (2009). *Bilimsel araştırma yöntemleri*. Anı.
King, D. L., Gradisar, M., Drummond, A., Lovato, N., Wessel, J., Micic, G., Douglas, P., & Delfabbro, P. (2013). The impact of prolonged violent video gaming on adolescent sleep: An experimental study. *Journal of Sleep Research*, *22*(2), 137–143.
Kirwil, L. (2009). Parental mediation of children's internet use in different European countries. *Journal of Children and Media, 3*(4), 394–409. https://doi.org/10.1080/17482790903233440
Kline, R. B. (2016). *Principle and practice of structural equation modeling* (4th ed.). The Guilford Press.
Levinthal, C., Kuusisto, E., & Tirri, K. (2021). How Finnish and Portuguese parents' implicit beliefs about learning actualize at home. *Frontiers in Education, 6*, 100.
Livingstone, S., & Helsper, E. J. (2008). Parental mediation of children's internet use. *Journal of Broadcasting & Electronic Media, 52*(4), 581–599. https://doi.org/10.1080/08838150802437396
Livingstone, S., Mascheroni, G., Dreier, M., Chaudron, S., & Lagae, K. (2015). *How parents of young children manage digital devices at home: The role of income, education and parental style.* EU Kids Online, LSE.
Livingstone, S., Ólafsson, K., Helsper, E. J., Lupiáñez-Villanueva, F., Veltri, G. A., & Folkvord, F. (2017). Maximizing opportunities and minimizing risks for children online: The role of digital skills in emerging strategies of parental mediation. *Journal of Communication, 67*(1), 82–105.

Marsh, H. W., & Hau, K. T. (1996). Assessing goodness of fit: Is parsimony always desirable? *The Journal of Experimental Education, 64*(4), 364–390. https://doi.org/10.1080/00220973.1996.10806604

McCarrick, K., & Li, X. (2007). Buried treasure: The impact of computer use on young children's social, cognitive, language development and motivation. *AACE Journal, 15*(1), 73–95.

McKenney, S., & Voogt, J. (2012). Teacher design of technology for emergent literacy: An explorative feasibility study. *Australasian Journal of Early Childhood, 37*(1), 4–12.

McKillup, S. (2012). *Statistics explained: An introductory guide for life scientists* (2nd ed.). Cambridge University Press.

Mesch, G. S. (2009). Parental mediation, online activities, and cyberbullying. *Cyber Psychology & Behavior, 12*, 387–393.

Murphy, K., & Davidshofer, C. (1994). *Psychological testing: Principles and applications* (3rd ed.). Prentice-Hall.

Nikken, P., & Jansz, J. (2014). Developing scales to measure parental mediation of young children's internet use. *Learning, Media and Technology, 39*(2), 250–266. https://doi.org/10.1080/17439884.2013.782038

Nikolopoulou, K., & Gialamas, V. (2015). ICT and play in preschool: Early childhood teachers' beliefs and confidence. *International Journal of Early Years Education, 23*(4), 409–425.

OECD (2020), *OECD Draft Recommendation on Children in the Digital Environment*: Revised Typology of Risks, https://one.oecd.org/document/DSTI/CDEP/DGP(2020)3/en/PD

Papadakis, S., & Kalogiannakis, M. (2017). Mobile educational applications for children. What educators and parents need to know. *International Journal of Mobile Learning and Organisation (Special Issue on Mobile Learning Applications and Strategies), 11*(3), 256–277.

Papadakis, S., & Kalogiannakis, M. (2020). A research synthesis of the educational value of self-proclaimed Mobile educational applications for young age children. In S. Papadakis, & M. Kalogiannakis (Eds.), 3324 Education and Information Technologies (2021) 26:3293–3326. *Mobile learning applications in early childhood education* (pp. 1–19). IGI Global. https://doi.org/10.4018/978-1-7998-1486-3.ch001

Papadakis, S., Foteini, A., & Nikolaos, Z. (2021). Mobile device use among preschool-aged children in Greece. *Education and Information Technologies*. https://doi.org/10.1007/s10639-021-10718-6

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016). Improving mathematics teaching in kindergarten with realistic mathematical education. *Early Childhood Education Journal, 45*(3), 369–378.

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018). Educational apps from the Android Google play for Greek preschoolers: A systematic review. *Computers & Education, 116*(139), 160. https://doi.org/10.1016/j.compedu.2017.09.007

Piotrowski, J. T. (2017). The parental media mediation context of young children's media use. In R. Barr, & D. N. Linebarger (Eds.), *Media exposure during infancy and early childhood: The effects of content and context on learning and development* (pp. 205–219). Springer. https://doi.org/10.1007/978-3-319-45102-2_13

Rummel, R. J. (1988). *Applied factor analysis*. Northwestern University Press.

Steinkuehler, C. (2010). Video games and digital literacies. *Journal of Adolescent & Adult Literacy, 54*(1), 61–63.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Pearson Education.

Tarrant, K., & Nagasawa, M. (2020). New York Early care and education survey: Understanding the impact of COVID-19 on New York early childhood system. https://educate.bankstreet.edu/sc/2

Tavşancıl, E. (2005). *Tutumların ölçülmesi ve SPSS ile veri analizi*. Nobel Yayın Dağıtım.

Turow, J., & Nir, L. (2000). The internet and the family: The view of U.S. parents. In C. Feilitzen, & U. Carlsson (Eds.), *Children in the new media landscape* (pp. 331–348). Nordicom.

UNİCEF. (2020). *Rethinking screen-time in the time of COVID-19*. https://www.unicef.org/globalinsight/stories/rethinking-screen-time-time-covid-19. Accessed May 20, 2021

UNSDG. (2020). *The impact of COVID-19 on children.* United Nations. https://unsdg.un.org/resources/policy-brief-impact-covid-19-children. Accessed April 20, 2021

Valkenburg, P. M., Krcmar, M., Peeters, A. L., & Marseille, N. M. (1999). Developing a scale to assess three styles of television mediation: "Instructive mediation", "restrictive mediation", and "social co-viewing". *Journal of Broadcasting & Electronic Media, 43*, 52–66. https://doi.org/10.1080/08838159909364474

Vaughan, M., & Beers, C. (2017). Using an exploratory professional development initiative to introduce iPads in the early childhood education classroom. *Early Childhood Education Journal, 45*(3), 321–331. https://doi.org/10.1007/s10643-016-0772-3

Wack, E., & Tantleff-Dunn, S. (2009). Relationships between electronic gameplay, obesity, and psychosocial functioning in young men. *Cyberpsychology & Behavior, 12*(2), 241–244. https://doi.org/10.1089/cpb.2008.0151

Warren, R. (2001). In words and deeds: Parental involvement and mediation of children's television viewing. *The Journal of Family Communication, 1*, 211–231. https://doi.org/10.1207/S15327698JFC0104_01

Yong, A. G., & Pearce, S. (2013). A beginner's guide to factor analysis: Focusing on exploratory factor analysis. *Tutorials in Quantitative Methods for Psychology*, *9*(2), 79–94. https://doi.org/10.20982/tqmq.09.2.p079

Zaranis, N., Kalogiannakis, M., & Papadakis, S. (2013). Using mobile devices for teaching realistic mathematics in kindergarten education. *Creative Education, 4*, 1–10.

# Chapter 24
# Equity Pedagogies for Preschool Family Engagement in Science and Engineering

**Hannah A. Kye**

**Abstract** Around the world, the demand for scientists and engineers grows while institutions struggle to provide more equitable STEM education and opportunities. The global movement for equity and diversity in STEM has implications for early childhood educators' local teaching practices. An early childhood teacher educator describes the guiding principles and process of developing an equity-focused program in collaboration with diverse preschool families and teachers. The research-based program, called Family Science and Engineering Nights, used culturally responsive pedagogy as a framework for instruction and family engagement. The program made innovative, bilingual science and engineering encounters (testing hovercrafts, improving simple robots) available to 375 preschool children and their families. This chapter proposes strategies to enhance engagement with traditionally marginalized families through science and engineering education. Implications include considerations for applying a culturally responsive framework to global trends in STEM research and practice, including early childhood engineering, making, and tinkering. This work advances discourses on pedagogy in early childhood STEM education by deepening connections to an equity framework and family engagement.

**Keywords** Family engagement · Culturally responsive pedagogy · Science nights

## 24.1 Introduction

Recognizing the importance of science and engineering in the global economy, school systems around the world have developed a variety of approaches to increase students' access to these disciplines. International organizations have called for equitable and inclusive approaches to inform these efforts, particularly in disadvantaged regions

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around the world (The United Nations Educational, Scientific, and Cultural Organization (UNESCO), 2021; World Federation of Engineering Organizations, 2018). While governments often focus on the teachers and schools within their purview, less emphasis is placed on the role of the family in improving science and engineering outcomes. However, survey data from 15 countries suggests that parents' attitudes towards science have a significant effect on their children's science achievement (Perera, 2014), and parental expectations are a key factor in participation in science and engineering (Organization for Economic Cooperation and Development (OECD), 2019; UNESCO, 2021).

The current chapter advances discourse at the intersection of family engagement, early childhood STEM education, and issues of equity and diversity. In collaboration with preschool families and teachers, a university professor developed a series of Family Science and Engineering Nights ("Science Nights"). During one school year, the four Science Nights included engineering design challenges such as testing hovercrafts and simple robots. The program illustrated the tenets of culturally responsive pedagogy (CRP) as applied to recent advances in STEM education, including early childhood engineering, making, and tinkering. This approach modeled inclusive and immersive STEM instruction in which preschool children and their families actively engaged in scientific discourse and processes. The pedagogical approach has implications for critical challenges in research and practice in early childhood STEM education. Following a discussion of issues and approaches to equity in early childhood STEM education, the Science Nights program is presented using the five tenets of the culturally responsive framework to illustrate the process of applying theory to practice. The goal of this chapter is to convey a theory and model to practitioners seeking to apply equity frameworks in their early childhood STEM teaching.

## 24.2 Issues of Equity and Diversity in Early Childhood STEM

In STEM, a culturally responsive framework is the critical examination of the barriers, policies, and practices that contribute to science and engineering outcome gaps, which vary across countries. In the US, despite recent legislation for universal pre-Kindergarten, culturally and linguistically diverse families seeking high quality early childhood education for their children face language barriers, diminished access to programs in segregated neighborhoods, and racial and ethnic discrimination. Structural discrimination encompasses school policies and practices aimed at perceived deficiencies, including knowing or learning multiple languages. These structures lead to large gaps in science achievement for black and Hispanic students in national studies of elementary students (Morgan et al., 2016; Quinn & Cooc, 2015). This is a public concern due to the growth and prestige of science occupations (Achieve, 2013). Clearly, structural solutions are necessary to change the inequities responsible for students' outcome gaps. However, CRP provides meaningful ways to invest in the academic success of traditionally marginalized learners and improve their classroom experiences.

While scholars such as Gay (2015) and Ladson-Billings (1995) established culturally responsive and culturally relevant education in the US, the framework is relevant for international contexts. As in the US, educators around the world should attend to local contexts, school demographics, and cultural understandings in order to inform educational decisions (Gay, 2015). CRP aligns with recent literature that recognizes STEM education as mediated by cultural, linguistic, and social factors (Barton & Tan, 2018; Rodriguez, 2015; Tobin, 2015). Importantly, the framework prompts questions about who is represented in school STEM curriculum and who is included in school STEM decision-making.

## 24.3 Engaging Families as Equity Pedagogy in Early Childhood STEM

Parents are a primary influence in children's development, and family engagement has been shown to improve children's outcomes, learning, and development (Garbacz et al., 2017; Kraft & Dougherty, 2013). Thus family engagement is commonly used as a strategy to improve outcomes for disadvantaged families (Ishimaru, 2019). In countries such as the United States, United Kingdom, and Australia, disadvantaged families are primarily identified by socioeconomic characteristics, which correlate with children's enrollment in valuable early childhood services (Grace et al., 2014). In OECD member countries, including Spain, Finland, and Portugal, educational policies and institutions seek to engage families and communities to boost educational quality and more equitable outcomes (Paz-Albo Prieto, 2018).

In the United States in particular, consistent gaps in science outcomes exist across lines of race and culture in terms of standardized test scores, enrollment in high school science courses, and entrance into science occupations (National Center for Education Statistics, 2015; National Science Foundation, 2017). In response to these gaps, Morgan et al. (2016) state, "Interventions designed to address science achievement gaps in the United States may need to be implemented very early in children's development" (p. 31). In particular, recent scholarship has called for interventions delivered before the primary grades that provide access to informal science learning and support family involvement for at-risk populations (Lee et al., 2014). While family literacy programs have grown across the globe in response to early gaps in language arts (Rabkin et al., 2018; Wasik, 2012), family science and engineering programs remain rare in both research and practice.

Of the few examples of family STEM programs in the literature, Yanowitz and Hahs-Vaughn (2016) assessed adult perceptions of family science nights. In the study, 15 middle and high school teachers participated in a two-week summer institute on STEM and were tasked with developing and implementing a family science night in their respective schools. Despite initial reservations, all teachers indicated after the event that they would execute another family science night and parents indicated that they had positive experiences and learned more about their children's interests and abilities in science. In a study of elementary teacher candidates, Dani et al. (2018) found that candidates' facilitation of family science nights fostered their appreciation of family-engaged, informal learning experiences. While these studies pointed to the value of family STEM programs, other studies have advanced this work by applying a lens of equity and diversity. For example, Bottoms et al. (2017) found that Family Math and Science Nights allowed elementary teacher candidates to see bilingualism as a benefit for learning: "Instead of a traditional view of an individual ELL child in a classroom who needs extra help and is vulnerable to low achievement without special services, at FMSNs the…family members and university students bilingually made meaning together about science" (p. 12–13). The authors noted that the FMSN itself did not necessarily result in transformed understandings or practices, but that it served as one of multiple critical engagements with reflection, theory, and practice toward developing culturally responsive pedagogy. In another program, Sullivan and Hatton (2011) discussed an inquiry-based approach to Family Math and Science Nights which focused on birds for second graders and on engineering for fourth graders. They found that "by engaging parents in the learning together with their children, we build a community of learners of all ages at our school and also create an environment for improved student achievement" (p. 59). The authors' primary focus was on an inquiry approach rather than diversity, however they briefly suggested providing parent information in multiple languages and having bilingual facilitators at events. The current project built on these important recommendations by applying an equity framework throughout.

## 24.4 The Preschool Family Science and Engineering Nights

### *24.4.1 Understanding the Context*

The Science Nights took place after school in two urban public preschools in the state of New Jersey in the US. The New Jersey Department of Education classified the school district as District Factor Group "A," a designation for the lowest socioeconomic status of citizens in the state. Thirty-two percent of the city's residents had an income level below the poverty level, which was almost triple the average poverty rate in the US. The city was predominantly Hispanic or Latino (43.6%), Black or African American (35.5%), and White (32.6%) (US Census, 2010). The majority of families whose children attended the two preschools in the district spoke Spanish as a first language, represented Latinx communities, and experienced lower incomes. The program was a small but important effort to work against the continuing marginalization of children from underserved urban communities.

The concerns of school families and teachers drove the development of the Science Nights. A district assessment found that parents wanted evening events focused on parent involvement, while teachers in the school lamented the lack of science curriculum. The teachers' concerns pointed to a critical challenge in early childhood STEM education: Due to historical and current socioeconomic inequities (Ladson-Billings, 2006) including racially-biased housing and school zoning policies, children of color are more likely to attend schools with fewer social and material resources for supporting interest and engagement in science and technology.

The university professor partnered with the principals, community engagement specialist, and master teachers in the preschools to schedule four Science Nights. Four planning meetings took place during the school year, which were open to all in-service teachers, preservice teachers (university students with field placements in the preschools), and parents/caregivers. While several families expressed interest in helping to plan the Science Nights, the group was ultimately unsuccessful in gaining parent participation during the planning meetings. Recruiting families for the planning process would be essential for future approaches to culturally responsive STEM.

The format of the current project was adapted from Sullivan and Hatton's (2011) approach: each evening event had two parts, including opening activities (5–6 brief activities at stations) and a challenge (1–2 longer investigations). Each event took place from 5:30 to 7:00 PM. The themes were connected to the state preschool standards and included Fall Fair, Air and Hovercrafts, Bot Building, and Float Festival. All 375 preschool children received paper invitations and phone messages sent to their families regarding the event. Attendance at each event varied between 40 and 71 preschool children plus their siblings and caregivers.

### *24.4.2 A Framework to Guide Pedagogical Approaches*

The Science Nights were based on the objectives of culturally responsive pedagogy (CRP) which include fostering both cultural competence and academic achievement (Gay, 2015). Ill-informed approaches to cultural diversity in STEM may incorporate historical examples, such as ancient accomplishments in agriculture; however this approach further marginalizes nonmainstream scientists and engineers (Lee & Buxton, 2010). Instead, approaches to STEM should reflect the following tenets of CRP:

1. Developing a knowledge base about cultural and linguistic diversity
2. Including ethnic and cultural diversity content in the curriculum
3. Demonstrating caring and building learning communities
4. Communicating with culturally and linguistically diverse students
5. Responding to ethnic diversity in the delivery of instruction (Gay, 2010).

For educators, the work of fostering STEM knowledge and skills is not separate from understanding children in the context of their families and communities. Early childhood educators who use a framework of CRP connect STEM to students' "funds of knowledge" (González, 2005), provide multiple modes of participation, and adapt to students' levels of language proficiency.

Based on the tenets of culturally responsive pedagogy, the Science Nights were designed to promote science learning in both English and home languages and to provide families with ideas for extending science learning at home. While science and engineering have often been associated with expensive equipment, this program provided at-home extension activities using simple and inexpensive "found objects" (materials easily found in students' homes and neighborhoods) to show how science and engineering related to children's lives. For example, at the end of the Air and Hovercraft night, children received a bag of materials to build an airplane at home and discussion prompts to continue conversations about air at home as they encounter bubbles, hairdryers, balloons, and fans.

## 24.5 Equity Pedagogies to Support Family Engagement in STEM

### *24.5.1 Developing a Knowledge Base About Cultural and Linguistic Diversity*

Typically, science and engineering have been taught as neutral, objective disciplines using pre-made kits or one-time experiments without connection to prior knowledge and experiences (Emdin & Lee, 2012). However the first tenet of CRP required that educators view STEM as family-engaged from the start.

During the planning meetings, in order to build the collective knowledge base about the cultural and linguistic diversity of families, in-service teachers shared about informal conversations with families, and preservice teachers shared information from family interviews they had conducted as part of the professor's coursework. The purpose of the family interviews was to learn: Who are our children and families? What interests, skills, values, and goals do they bring to school? From the family interviews, the planning group learned that most families in the school had immigrated from Mexico, Puerto Rico, and Guatemala; and several families expressed deep pride in being both American and Latinx. The interviews also revealed considerable linguistic knowledge among families, who represented a wide range of English language proficiency. Based on the interviews and informal conversations with children, the teachers and professor found common themes in children's interests: weather and seasons, making things, and experiments. A clear and consistent finding was families' value of education and desire to see their children do well in school. The planning group found that children were already engaging in science and engineering in their homes and communities through cooking and baking, caring for animals and plants, and visiting the nearby zoo. These findings allowed the educators to begin with families' strengths at the center of their planning process.

### 24.5.2 Including Ethnic and Cultural Diversity Content in the Curriculum

In her seminal work on anti-bias science education, Lee (2005) writes, "If their home languages and cultures are not considered in the educational process, schooling ignores or even negates the tools that students have used to construct their understandings of the world" (p. 494). Due to biases deeply engrained in society, teachers commonly hold deficit views of nonmainstream children. The content of the Science Nights contradicted deficit views of culturally and linguistically diverse children. Each event was filled with materials showing the cultural richness and contributions of people and communities who shared the families' backgrounds.

The family interviews presented the need to learn about STEM from a variety of cultural perspectives. The educators in the planning group were highly motivated to expand their prior knowledge of science and engineering. The following questions served as a guide: Whose work do we know? What resources can strengthen the ethnic and cultural diversity of our curriculum? The group was committed to supporting families' pride in being both American and Latinx, thus they sought resources that valued both past and current advances by scientists and engineers who shared their backgrounds. During class, the professor and preservice teachers found books and created resources, such as trading cards and posters, that highlighted Latinx individuals as capable creators, inventors, and problem-solvers. One of the preschool fathers asked for the list of books at the event and noted he could have spent the entire evening reading the books to his daughters. Through this approach, educators framed the content and activities of STEM in ways that could be meaningful to students who were typically underrepresented in school curriculum.

### 24.5.3 Demonstrating Caring and Building Learning Communities

A culturally responsive approach involves humanizing practice that "respects the human, interpersonal side of teaching, and emphasizes the richness of the teacher-student relationships" (Huerta & Brittain, 2010, p. 385–386). While some science interventions focus on increasing student content knowledge, the Science Nights aimed to support family engagement and interest in STEM. The planning group identified multiple barriers between families and STEM, including the low priority of science in the preschool curriculum, the difficulty of attending evening events, and the dominant perception of STEM as disciplines for the elite in the US. Thus the guiding question for community-building during the Science Nights was: What traditions or small celebrations would reduce barriers between children's worlds and the worlds of science and engineering? The professor shared that in other programs, she had helped to plan annual science sing alongs, mini maker faires, and science parades for children to show what they had learned and made. These helped to establish a shared culture of science, engineering, making, and tinkering.

For the first Science Night, the educators agreed on the simple approach of providing family dinner and playtime. Based on positive feedback from families, they continued this tradition in the remaining Science Nights. After one hour of intensive science and engineering challenges taking place in multiple rooms in the preschool, the attendees gathered in one room to share a meal. Children called their parents over to sit by their teacher or student teacher, reflecting on the evening together and sharing about their weekend plans. After a pizza party during one Science Night, a teacher set out a large parachute, tossed balloons on top, and invited parents, kids, teachers, professor, and principals to hold loops of the parachute to give it a shake and dance in circles together. By prioritizing time for interpersonal connections, the Science Nights enriched educator-family relationships.

### *24.5.4 Communicating with Culturally and Linguistically Diverse Students*

Science and engineering teachers who work with students from Latinx backgrounds must address three distinct cultures along with the languages of STEM, Spanish, and English (Suriel, 2014). For the Science Nights, a guiding question was: How can we make linguistic access a priority when teaching science and engineering? The planning group discussed how science teachers and makerspace facilitators do not often think of themselves as language teachers. However for students who are learning English, all teachers serve as language teachers regardless of their intention.

During class, the preservice teachers wrote Science Night station directions, discussion questions, and vocabulary words in Spanish and English to prepare to support conversations and connections in home languages. They identified STEM vocabulary words that were similar in English and Spanish, which could be used to support language proficiency in the content areas. In order to ensure linguistic access for families, the planning group assigned one translator or Spanish-speaking teacher to each learning station at the events. In response, children enthusiastically spoke and sang in Spanish as they worked. One chimed, “Work con mamá, work con mama,” as he worked on a clay structure. Another sang out, “Ya terminamos de crear, es la última. Ay chelín-chelín-chelín.” Rather than using hushed or apologetic tones, families engaged in fervent discussions in Spanish and English about the strength of structures and materials as they tinkered together.

During the Science Nights, the educators used English language learning strategies to support children and families’ participation. Multiple modes of representation included teacher demonstrations, oral, pictorial, and written information. Teachers also activated families’ prior knowledge by asking them to contribute connections and ideas to large easel paper, with examples already provided in English, Spanish, and drawings. These approaches provided multiple access points to the science and engineering content and discussions.

### *24.5.5 Responding to Ethnic Diversity in the Delivery of Instruction*

In the classroom, culturally responsive teachers may facilitate peer-teaching to respond to ethnic diversity in the delivery of instruction. Peer teaching gives educators an opportunity to learn how students name their processes and to hear them use their cultural lexicon, references, and examples. During the Science Nights, educators setup opportunities for children to lead their families and for families to lead their children in the learning. This approach is similar to how one might pre-teach vocabulary or content to students who are learning English before the lesson. For example, at the event focused on Bot-Building, one station focused on artistic uses of wire. Teachers at this art-and-science station showed children cards featuring different wire artists and examples of wire creations. They gave children a preview of the wire art activity and resources before inviting their families to join the child, who would now take on the role of the teacher. At another station at the same event, families received the preview: the professor prepared a card with key words and translations of questions to ask while children were tinkering with circuits.

For the Science Nights, families needed to be invited to collaborate and build the curriculum during the evening events. Thus the professor and teachers planned open-ended experiences, discussion questions, and displays that asked families for their insights and expertise throughout the Science Night activities. One station had a pile of construction materials and the mission of building a space to read books. Children had unstructured time to build, and then they presented their process of designing, testing, and redesigning the book nooks to parents, teachers, and peers. These impassioned presentations helped educators to clearly recognize the maker capacities of culturally and linguistically diverse students.

## 24.6 Discussion and Implications

This chapter provided an equity-focused lens, guiding questions, and insight on early childhood science and engineering education. It addressed the critical issue of equity and strengthened connections between STEM, family engagement, and culturally responsive pedagogy. This work has implications for education practice and future research.

### 24.6.1 Implications for Educational Practice

For the professor, a key goal was to support teachers' and administrators' capacities for equity-oriented education and push forward conversations about diversity in STEM education. These advances in the conversation are brought to life through the Science Nights, which reveal how making, tinkering, and investigating are not neutral encounters with science but imbued with culture and language. This work has implications for educators around the world who are working to build effective and equitable STEM programs for young children.

In the US, there is a dominant perception that certain characteristics of scientists and engineers, "such as being reserved, objective, and 'well-behaved,' are categorically not urban, Black, or Latino/a" (Emdin & Lee, 2012, p. 12). Through the simple tradition of family dinner and playtime, the Science Nights established an alternative culture of STEM which encouraged loud singing in Spanish and boisterous dancing with teachers. Programs can similarly identify context-specific barriers between families and STEM, and plan ways to reach across those barriers. Scholars such as Barton (2000) assert that educators must move away from traditional ideas about what students "need to know" in STEM, so they can craft curriculum and pedagogy that is responsive to the needs of their students. During the Science Nights, families and educators were encouraged to contribute to the culture, connections, and content. Similarly, equity-oriented programs can identify detrimental perceptions about who can be a scientist or engineer in their local context, and invite families into the work of establishing a new culture of STEM in their schools.

A particular challenge of the Science Nights was gaining family representation in the planning group. While the family interviews provided important insights, future approaches should prioritize family engagement at the planning level. In other STEM programs, the professor used documentation and teacher invitations to increase family engagement at the planning level. Documentation, such as bulletin boards and email newsletters, shared recent STEM learning in classrooms and invited input and suggestions from families. Teacher invitations were both verbal and sent electronically with the message that families were needed for the program. Such invitations helped families understand that they were wanted and that they had knowledge and skills to contribute to the program. Similarly, future approaches should design systems of gaining input from traditionally marginalized families and include them in each step of the learning process.

### 24.6.2 Implications for Future Research

Demand for scientists and engineers around the world is high, and UNESCO (2021) calls for institutions to work together to ensure that more young people consider engineering as a career. As the trends of engineering, making, and tinkering make their way into early childhood classrooms, it is crucial to prepare teachers to view this work through a lens of equity. Future research would do well to identify ways to support teacher candidates' development of culturally responsive science and engineering pedagogies. Studies should explore approaches that help teachers recognize the STEM capacities of racially, culturally, and linguistically diverse students and view them as capable makers, thinkers, and problem-solvers. In addition, further research is needed on the outcomes of science and engineering interventions for young children, particularly those with equity-frameworks. Studies of impacts on children, teachers, and families are needed to develop an evidence base to inform future practice in this area.

## References

Bottoms, S. I., Ciechanowski, K., Jones, K., de la Hoz, J., & Fonseca, A. L. (2017). Leveraging the community context of Family Math and Science Nights to develop culturally responsive teaching practices. *Teaching and Teacher Education, 61*, 1–15.

Dani, D. E., Hartman, S. L., & Helfrich, S. R. (2018). Learning to teach science: Elementary teacher candidates facilitate informal STEM events. *The New Educator, 14*(4), 363–380.

Emdin, C., & Lee, O. (2012). Hip-hop, the "Obama effect," and urban science education. *Teachers College Record, 114*(2), 1–24.

Garbacz, S. A., Herman, K. C., Thompson, A. M., & Reinke, W. M. (2017). Family engagement in education and intervention: Implementation and evaluation to maximize family, school, and student outcomes. *Journal of School Psychology, 62*(1), 1–10.

Gay, G. (2015). The what, why, and how of culturally responsive teaching: International mandates, challenges, and opportunities. *Multicultural Education Review, 7*(3), 123–139.

González, N. (2005). Beyond culture: The hybridity of funds of knowledge. In N. González, L. C. Moll, & C. Amanti (Eds.), *Funds of knowledge: Theorizing practices in households, communities, and classrooms* (pp. 29–46). Routledge.

Grace, R., Bowes, J., & Elcombe, E. (2014). Child participation and family engagement with early childhood education and care services in disadvantaged Australian communities. *International Journal of Early Childhood, 46*(2), 271–298.

Huerta, T. M., & Brittain, C. M. (2010). Effective practices that matter for Latino children. In E. G. Murillo, S. A. Villenas, R. T. Galván, J. S. Muñoz, C. Martínez, & M. Machado-Casas (Eds.), *Handbook of Latinos and education: Theory, research, and practice* (pp. 382–399). Routledge.

Ishimaru, A. M. (2019). From family engagement to equitable collaboration. *Educational Policy, 33*(2), 350–385.

Kraft, M. A., & Dougherty, S. M. (2013). The effect of teacher–family communication on student engagement: Evidence from a randomized field experiment. *Journal of Research on Educational Effectiveness, 6*(3), 199–222.

Ladson-Billings, G. (1995). But that's just good teaching! The case for culturally relevant pedagogy. *Theory into Practice, 34*(3), 159–165.

Lee, O. (2005). Science education with English language learners: Synthesis and research agenda. *Review of educational research, 75*(4), 491–530.

Lee, O., Miller, E. C., & Januszyk, R. (2014). Next generation science standards: All standards, all students. *Journal of Science Teacher Education, 25*(2), 223–233.

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher, 45*(1), 18–35.

OECD. (2019). *Why don't more girls choose STEM careers?* Organisation of Economic Co-operation and Development. www.oecd.org/gender/data/whydont-more-girls-choose-stem-careers.htm

Paz-Albo Prieto, J. (2018). Enhancing the quality of early childhood education and care: ECEC tutors' perspectives of family engagement in Spain. *Early Child Development and Care, 188*(5), 613–623.

Perera, L. D. H. (2014). Parents' attitudes towards science and their children's science achievement. *International Journal of Science Education, 36*(18), 3021–3041.

Quinn, D. M., & Cooc, N. (2015). Science achievement gaps by gender and race/ethnicity in elementary and middle school: Trends and predictors. *Educational Researcher, 44*(6), 336–346.

Rabkin, G., Geffers, S., Hanemann, U., Heckt, M., & Pietsch, M. (2018). Hamburg's Family Literacy project (FLY) in the context of international trends and recent evaluation findings. *International Review of Education, 64*(5), 651–677.

Sullivan, J., & Hatton, M. (2011). Math and science night. *Science and Children, 48*(5), 58–63.

UNESCO. (2021). Reimagining our futures together—A new social contract for education. Report from the International Commission on the Futures of Education, 2021.

Wasik, B. H. (Ed.). (2012). *Handbook of family literacy*. Routledge.

World Federation of Engineering Organizations. (2018). WFEO engineering 2030. A plan to advance the achievement of the UN Sustainability Goals through engineering. Progress Report No. 1. WFEO. www.wfeo.org/wp-content/uploads/un/WFEO-ENgg-Plan_final.pdf

Yanowitz, K. L., & Hahs-Vaughn, D. L. (2016). Adults' perceptions of children's science abilities and interest after participating in a family science night. *School Science and Mathematics, 116*(1), 55–64.

# Chapter 25
# Perceptions About STEM and the Arts: Teachers', Parents' Professionals' and Artists' Understandings About the Role of Arts in STEM Education

**Maria Ampartzaki, Michail Kalogiannakis, Stamatios Papadakis, and Vasiliki Giannakou**

**Abstract** Educators', parents' and stakeholders' perceptions about STEM, STEAM, female representation, and underachievement in STEM are of critical importance, as these perceptions shape educational practices. This study presents the results of a survey conducted to explore the opinions of teachers, student-teachers, parents, artists, and STEM professionals. In summary, the results showed that: (a) although teachers, student-teachers, and STEAM professionals knew about the STEAM approach, only a few had the experience of implementing it; (b) the major difficulties educators faced in implementing STEAM relate to understanding the methodological principles of this approach and the lack of educational resources; (c) educators had received limited support by policymakers, advisers, etc.; (d) STEAM was expected to enrich the curriculum with hands-on and active learning and have a positive impact on children's critical thinking and communication skills, as well as their overall development; (e) STEAM is expected to increase the motivation and participation of girls and disadvantaged students; and (f) educators and parents recognise the vulnerability of disadvantaged students, but do not seem to be aware of female underachievement in STEM subjects and careers.

**Keywords** STEM · STEAM · Educators' perceptions · Stakeholders' perceptions · Underachievement · Gender bias

## 25.1 Introduction

The importance of Science, Technology, Engineering, and Mathematics (STEM) as core subjects has been recognized in recent years. STEM education has been an educational goal to prepare citizens for life and be part of the STEM workforce. Integrating science, technology, engineering, and mathematics (STEM) into

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early childhood education programs have also received significant attention as being fundamental. This interest is driven by several factors, such as decreasing student numbers in pursuing STEM professions or equipping children with skills for the digital age. This study examines the attitudes and readiness of early childhood education pre-service and service teachers to use art in teaching STEM in their educational practices with a view to engulf this process in teacher education programs. It also surveys parents' beliefs and attitudes regarding the STEAM subjects.

Moreover, it aims to detect teachers' and parents' beliefs on female underrepresentation and underachievement in STEM. Finally, it explores artists' and STEM female role models' contributions to the ongoing debate regarding increasing public and female interest in STEM subjects. The study was initiated within the context of a project funded by the Erasmus+ scheme. The project brought the title Next Generation Science Standards through STEAM (abbreviated to NGSS) and was funded as a Key Action 201 (Agreement No. 2020-1-TR01-KA201-094463) "strategic partnership for school education." The project's participant-organizations represent the following countries: Greece, Bulgaria, Romania, Poland, and Lithuania. The project coordinator is the Üsküdar District National Education Directorate. NGSS' primary goal is to "enhance, encourage and foster an innovative educational approach that integrates STEM+Arts learning in early childhood education through gender-inclusive methods and resources and promote a positive change of attitudes towards non-stereotyping choices in education." With this in mind, the project sets off with focus group interviews organized in each participant-organization to gather information about the issues of STEAM faced in each country. This study presents the results collected through focus groups in Greece. The uniqueness of this study is that it contributes to a field that is insufficiently researched in Greece. That is teachers' and stakeholders' perceptions about STEM in Early Childhood Education. Exploring perceptions held by teachers, parents, STEM professionals and other stakeholders is important since these are likely to influence the pedagogical choices made for children (see, for example, Baltsavias & Kyridis, 2020).

## 25.2 Theoretical Framework

### *25.2.1 STEM and STEAM in Education*

STEM as a curriculum approach aims at educating students in four specific disciplines: Science, Technology, Engineering, and Mathematics in a holistic and integrative way (Kennedy & Odell, 2014). The term was coined in the 1990s at the Interagency Meeting on Science Education at the National Science Foundation (NSF) in the United States (Sanders, 2009). A general deficiency of everyday knowledge of science, technology, and mathematics in the general population and the poor results of American test scores sparked speculation and led to a rationale for STEM. These subjects "were behind those of students in other industrialized nations." "Scientific and technological innovation has increased in importance since then. Therefore, developing students' STEM capabilities is necessary to enable them to succeed in the contemporary information-based and highly technological society" (Pimthong & Williams, 2021, p. 2).

The ultimate goal of STEM as a concept and a method of developing knowledge is to develop critical thinking, problem-solving, and creativity skills in students, which will make them more capable and competitive in the workforce (Lazonder & Harmsen, 2016). In STEM, the four disciplines are integrated, and this integrative approach results in a cohesive curriculum and holistic teaching and learning approaches (Morrison & Bartlett, 2009; White, 2014).

"STEM education was created to educate youth with the high-tech skills necessary for the expanding STEM job market" (Land, 2013, p. 552). Although educators and the industry highly appreciated this effort, experience and research have shown that recent graduates still lack creative and innovative skills (Land, 2013). Enhancing the STEM curriculum should continue, exploring new dimensions. This need was met by adding Arts to STEM education (hence, STEAM education) to complement convergent skills developed by STEM disciplines with the divergent skills promoted by Arts. It was realized that decomposing a complex problem demands convergent thinking, and then developing and applying a solution in real-world situations is led by divergent thinking.

Thus, STEAM stands for Science, Technology, Engineering, Art, and Mathematics, combining disciplines and techniques. It was created to transform education, encourage the integration of art and design in the school curriculum. The four STEM disciplines were connected, and artists and designers were employed and assigned to contribute to innovation. The STEAM approach attempts to combine theoretical and positive sciences with art as a connecting link. It creates learning experiences connected to everyday life and moving in the context of creativity and innovation (Catchen, 2013). Art was added to STEM subjects to encourage a transdisciplinary approach to raise students' interests and engage them in real-life problems (Jamil et al., 2018). Integration of Science, Technology, Engineering, Arts and Mathematics (STEAM) as a new trend can be quickly adopted and followed (Aldemir & Kermani, 2017; Moomaw & Davis, 2010). It has been observed that the comprehensive approach to even purely scientific problems through the establishment of links between positive and theoretical research areas leads to their successful treatment. At the same time, people who can make such leaps are more often characterized as creative (Henriksen, 2014). "Within an early childhood context, STEAM education means finding ways to explore these subjects in an integrated way through hands-on projects, books, discussions, experiments, art explorations, collaboration, games, physical play, and more" (Sullivan & Strawhacker, 2021, p. 89).

The STEAM approach offers students more than high-tech skills. Complex systems and solutions are conceptualized and designed with analytical skills. However, they must be transitioned and utilized into business and labor, requiring more creative skills. "New technological tools such as programmable robotics kits and programming languages designed for young children have become a popular way to teach interdisciplinary STEAM content by integrating arts and crafts, literacy, music, and more with engineering and robotics" (Sullivan & Strawhacker, 2021, p. 89; see also Barnes et al. 2020).

STEAM also has benefits for students' socio-emotional development. Integrating the arts into the STEM curriculum provides pathways for personal meaning-making and self-motivation. STEAM prepares students for life, regardless of the profession they choose to follow. For Church and Cohrssen (2021), social interaction is the locus of learning in early childhood. Opportunities for STEAM learning occur throughout the day, across activities, indoors, outdoors, with peers, teachers, and family members.

STEAM teaches students how to think critically and solve problems—skills that can be used throughout life. Critical thinking, creativity, collaboration, communication, flexibility and adaptability, initiative, organizational ability, empathy, social skills, problem-solving, digital, and technological literacy (the so-called 21st-century skills) are all developed within a STEAM context.

In summary, art, and creativity:

- Help students realize what works and what does not. They also provide students with opportunities to become risk-takers and deal with challenges.
- Drive students to become more sensitive to problems and the social dimension of the issues and more prone to searching for solutions.
- Cultivate divergent thinking by encouraging mixing materials, playing with perspectives, out-of-the-box and novel solutions.
- Demand attitudes such as focusing and commitment.
- Demand open-mindedness, openness to other perspectives, fluid thinking, and ease with ambiguity.

### *25.2.2 Equity in STEM*

Researchers claim that "global economies and societies need to integrate knowledge and skills into STEM to solve problems on an ongoing basis. The trend of future employment opportunities leads to the increasing need for at least a basic understanding and incorporation of mathematics and science" (Berisha & Vula, 2021, p. 1). Although it is common ground that economic engines and national security measures are built on STEM fields, students seem to be neither proficient nor interested in a STEM career. For example, according to official reports, "recent data from a test commonly taken by college-bound high school students found that only 20% are ready for courses typically required for a STEM major" (Committee on STEM Education of the National Science & Technology Council, 2018, p. 2). There are not enough people with strong STEM knowledge and skills to fill the demand for jobs. This is recognized in Western and developing countries where STEM jobs are increasing, and many are unfilled. In the EU, there is also a skills shortage in STEM fields despite high unemployment rates in many member states. STEM professionals are among the "top five skill shortage occupations" (European Centre for the Development of Vocational Training, 2016, p. 1). According to O'Leary et al. (2020), teaching and retention of students coming from disadvantaged backgrounds is a "long-standing challenge" (p. 7).

UNICEF's recent report confirms the global issue of gender underachievement and underrepresentation in STEM subjects and professional roles (United Nations Children's Fund, hereafter UNICEF, 2020). It highlights that, girls seem to be equally able to achieve "minimum proficiency levels in math and science" (p. 4). At the same time, regional data suggest that as they progress in Secondary and Higher Education, there are gender differences and differences "based on students' socio-economic status" (p. 5). It is noted that girls appear to "have lower self-confidence in their STEM abilities than boys in most countries" (p. 11). This is also related to limited "STEM engagement, interest, and enjoyment" (p. 12). Even among higher achievers, fewer female than male students plan to pursue STEM careers. All these seem to be linked to "gender norms, bias, and stereotypes" (p. 14). More research studies show a gender gap in course-taking and studying and pursuing careers in STEM subjects (Botella et al., 2019; McGuire et al., 2020). Other research confirms UNICEF's finding that women and girls are underrepresented in STEM careers even when they excel in those school subjects (Dasgupta & Stout, 2014).

A call for action to increase performance and equity in STEM subjects and professional roles both for girls and disadvantaged students includes the following remedy suggestions, among others:

- Develop gender-responsive and culturally responsive pedagogies accompanied by analogous career opportunities (O'Leary et al., 2020; United Nations Children's Fund & International Telecommunication Union, hereafter UNICEF & ITU, 2020).
- Scan and amend teaching and learning materials or processes to remove and eliminate stereotypes and biases (O'Leary et al., 2020; UNICEF & ITU, 2020).
- Raise awareness about social identities and provide appropriate role models (including instructors representing minority identities and female educators) to inspire students to aspire for a more equitable future (O'Leary et al., 2020; UNICEF & ITU, 2020).
- Build capacity and sustained mentoring (Glennie et al., 2019; Means et al., 2021; Subotnik et al., 2019).
- Take advantage of digital technology and connectivity to deliver STEM content to disadvantaged students (including girls) (Maris et al., 2018; UNICEF & ITU, 2020).
- Cultivate STEM interests within an inclusive environment that nurtures acceptance and engulfs students' reality (Subotnik et al., 2019).
- Collaborate with families to support children's participation in STEM activities (Kumar, 2016).

Researchers attempt an account of the reasons that seem to contribute to students' underachievement in STEM subjects. This brings up factors such as:

- The lack of qualified or appropriately prepared teachers (Akiri et al., 2021; Conradty & Bogner, 2019; Ejiwale, 2013).
- A lack in in-service development seminars (Ejiwale, 2013; Hammack & Ivey, 2019).
- Students' ill foundation and low inspiration in STEM subjects (Ejiwale, 2013; Ramsey & Baethe, 2013).
- The lack of STEM experiences in various environments (e.g., non-formal and informal settings) (Ejiwale, 2013; Scinski, 2014).
- The lack of school support (e.g., in terms of funding, resources, as well as a shared vision for STEM) (Ejiwale, 2013; see also Slavit et al., 2016).
- The lack of collaboration between STEM professionals, educators, and researchers will bring interdisciplinarity and guide the STEM integration and curriculum development (Dee & Gershenson, 2017; Ejiwale, 2013).
- Shortage in quality teaching guidelines and lesson plans (Ejiwale, 2013; Winangun & Fauziah, 2019).
- Poor teaching, learning, and assessment methods (Akiri et al., 2021; Ejiwale, 2013).
- Poor facilities and resources (Ejiwale, 2013; Hammack & Ivey, 2019).
- Lack of hands-on and work-based experiences for students or direct links with everyday experience (Ejiwale, 2013; Kelley & Knowles, 2016).
- Lack of knowledge and understanding of STEM careers (Blotnicky et al., 2018).

Other studies have shown the need for effective pre-service STEM preparation programs in preparing quality STEM teachers (Bartels et al., 2019). Research shows motivating, inspiring, and involving students in STEM disciplines and committing them to math and science directions. Education systems should adopt more innovative approaches in a context that students see as relevant and, in this way, are willing to deal with (Bissaker, 2014). "According to Harlow et al. (2018), teacher support is needed to develop appropriate skills to promote STEM learning experiences, as many teachers do not have pedagogical practices to teach STEM education. Milner-Bolotin (2018) notes that it is essential to review available research evidence on teacher knowledge development during teacher education and better understand how to educate STEM teachers" (Berisha & Vula, 2021, p. 2).

### *25.2.3 Teachers, Parents, and STEM Education*

Teachers are vital agents and implementers of new policies, approaches, strategies, or solutions. It is, therefore, essential for us to see how much they understand and uptake new pedagogies (Jamil et al., 2018).

"Primary school teachers need to understand STEM integration of the core disciplines based on real-world contexts by preparing well-designed STEM activities that promote student-centered learning" (Pimthong & Williams, 2021, p. 4). Educators' beliefs, attitudes, and self-perception of their competencies and skills towards

STEM teaching, apart from their content knowledge, play an essential role in delivering a STEM curriculum (Aldemir & Kermani, 2017). Many educators do not feel confident and are reluctant to provide STEM content (Cohrssen & Page, 2016; Hedlin & Gunnarsson, 2014). On the other hand, some actively teach STEM and seek ways to increase the frequency, effectiveness, and quality of their STEM lessons (Tippett & Milford, 2017). Research indicates that having confidence in teaching STEM (Bagiati & Evangelou, 2015) and educators' readiness to teach STEM (Park et al., 2017) positively influences education practices. Frequently, teachers are pressured to comply with strategies even if they are not convinced about their effectiveness and/or usefulness. They also face limitations imposed by practical problems and fit new ideas into an existing framework or workload. Inconsistencies are found between teachers' beliefs and actual practices regarding STEM and the Arts (Jamil et al., 2018; Park et al., 2016).

Children need to be interested in STEM and have a positive perception of themselves as STEM learners. These dispositions develop from the early childhood years (Patrick et al., 2009). Educators' dispositions can influence them through teacher practice, curriculum, and pedagogical choices (Panizzon & Westwell, 2009). "Much research suggests students should engage with STEM while young to prompt and maintain their interest throughout schooling" (Pimthong & Williams, 2021, p. 4).

Additionally, according to Kuhn et al. (2016, p. 11), teachers can learn to use arts to enhance STEM learning in dynamic ways by:

- "Using creative processes to gain access to students' ideas before science content is taught, to help guide further instruction; and
- Using creativity as a means for students to express their understanding of science content".

The interdisciplinary and transdisciplinary approaches are in line with this purpose. Trans-disciplinarity means the multifaceted exploration of a topic that touches many disciplines and connects scientific fields. In addition to specific knowledge, the student can understand the "conversation" of science and its contribution to all aspects of everyday life (Matsagouras, 2012). The teaching content is not the subject of separate lessons that occur at various times each but learning unified and indivisible topics. During interdisciplinary and transdisciplinary teaching, students act on their own, and learning becomes experiential. Physical supervision is used extensively, and students learn through their reflection (Salvaras, 2004).

As problem-solving is a fundamental part of every STEAM project, students need many opportunities to develop the skills necessary to approach and answer diverse types of problems. Teachers' appropriate problems in a STEAM project should embody features. These should be based on students' interests, motivate students to understand concepts deeper, make reasoned decisions, and defend them. They should connect the content to earlier knowledge and have an appropriate level of complexity to ensure that the students can solve it. They must also include open-ended steps that will enable students to engage with the problem freely. Overall, Arts expand the learner's potential and cultivate thinking manners, attitudes, habits, and skills essential to the STEM subjects (Conradty & Bogner, 2019; Conradty et al., 2020). Introducing and maintaining an Art-oriented environment and methodological approach to the STEM subjects also means adopting an inquiry-based approach to learning. Art is a process of open inquiry, which is also essential to deep and rich scientific thinking and reasoning (Conradty & Bogner, 2020).

Thus, based on the above (see also McClure et al., 2017), effective inclusion in STEM should strive to:

1. Initiate meaningful experiences which are believed to "promote a greater interest in science" (MacDonald et al., 2020, p. 354).
2. Use developmentally appropriate technology, especially with vulnerable children or children who have restricted access to technology (Aguilera & Ortiz-Revilla, 2021; van Keulen, 2018).
3. Encourage learning-by-doing. "Research has shown that providing meaningful hands-on STEAM experiences for early childhood and elementary age children positively impacts their perceptions and dispositions towards STEAM" (DeJarnette, 2018, p. 19).
4. Involve parents "in improving early childhood science experiences, parents can be a powerful ally" (Vahey et al., 2019, p. 17).

Studies have shown that STEM education should have an expanded role early in a child's life to nurture attitudes and skills that will initiate further interest and success later in school (Hachey, 2020). Learning at home can equally support this early development (McClure et al., 2017). Parents and the wider public are also essential agents in promoting STEM subjects and their children's STEM interests, especially when it comes to girls' motivation (Dasgupta & Stout, 2014). Parents are active agents and substantially influence the child's career choices than the peer network or the school (Peterson, 2017). Since stereotyping, lifestyle, and preferences play an essential role (Shapiro & Williams, 2012; Wang & Degol, 2017), parents' beliefs and attitudes can matter greatly. It is even reported that parents (like teachers) might "experience anxiety, low self-confidence, and gendered assumptions about STEM topics, which can transfer to their children" (McClure et al., 2017).

## 25.3 Methodology

The main goal of the present study was to bring up and explore the perceptions about Art in STEM held by Greek teachers, student teachers, STEM professionals, artists, and parents. More specifically, this research endeavor had the objective to detect participants' insights, perceptions, and understandings in the following matters, and this, ultimately, provides the framework for asking appropriate questions:

- The difference between STEM and STEAM and the essence of each approach (the essential characteristics).
- Difficulties educators come across in implementing either STEM or STEAM in the current educational settings.

- The ways educators overcome the above difficulties and people who support these efforts.
- Educators' perception of their readiness for implementing the STEAM approach and their training needs.
- Expectations from the STEAM implementation and what is perceived to be a "good practice" in STEAM.
- The expected effects of STEM implementation on children.
- Whether students' socio-emotional development is taken into account in STEAM or Science lessons.
- The perception of STEAM's role in increasing motivation and participation of girls in the STEM fields of study and careers.
- Measures participants take to increase girls' and disadvantaged students' participation in STEAM.
- Concerning parents, the study also aimed at investigating whether they hold biased perceptions of gender differences in toy, program, and activity selection.

The above objectives and the questions addressed to the focus groups were defined and drafted by the NGSS project team with the researchers' participation in the present study. They also undertook the responsibility of executing focus groups interviews in Greece.

According to the requirements of the NGSS project, we targeted a small sample to develop a case study on the matter. The technique of focus groups interviews as a method of data collection was selected by the NGSS project team. This selection was justified by the primary aim to detect opinions and perceptions shared or negotiated by the participants. Focus groups should capture both the argument and interactions between the participants and result in collaboratively negotiated meanings (Sim & Waterfield, 2019). The sample of focus groups is purposefully selected, and outcomes are dynamic as opposed to the static contributions of individual interview data from a representative sample (O'Nyumba et al., 2018). Each of the focus groups we organized contained 4–5 persons (for the groups of teachers and student teachers), or 2–3 (in the smaller groups comprised of STEM professionals, artists, or parents). Each interview had a facilitator and an assistant (O'Nyumba et al., 2018) who observed and helped the participants to (a) sort out technical problems, (b) solve minor questions, (c) equally participate in the discussion, and have their say. S/he also supported the facilitator in the accurate recording of what the participants said. Each focus group interview started with a brief introduction. Participants were reminded of the interview scope and asked to confirm that they had read, understood, and signed the consent form. There were also reminded of the basic rules of the interview (respect for the others, use of non-sexist, non-offensive language, etc.). The researchers had agreed to protect the anonymity of the ideas and issues discussed during the interview. Next, the discussion moved on according to the list of critical questions developed by the researchers. During the interview, the facilitator and her/his assistant could reflect on what the participants said and probe further clarifications (O'Nyumba et al., 2018).

### 25.3.1 Data Analysis

Data were subjected to thematic analysis (Vaismoradi & Snelgrove, 2019). It started with open coding (Glaser, 2016). Similar codes were grouped into categories to reveal ideas, concepts, and issues (Lochmiller, 2021). At the final stage, categories were linked and formed themes. These themes became the basis for a richer account of the meanings revealed by the data (Vaismoradi & Snelgrove, 2019). All codes, categories, and themes were checked and discussed by us, the authors of the present study. Coding was repeated twice, that is, by two authors independently, and discussed points of disagreement until a consensus was achieved (Nowell et al., 2017).

### 25.3.2 Sample Composition

Based on the NGSS project plan, we interviewed five groups of agents: Teachers, student teachers, STEM professionals, artists, and parents. An open call was issued via publicity channels, which made the sampling method convenient. The educators' interviews were carried out online, using a variety of platforms, namely, Microsoft Teams, Zoom, or BigBlueButton (according to the access rights participants could be granted). This was due to the quarantine imposed by the Government to prevent the spread of COVID-19. Artists, professionals, and parents had the opportunity to attend a face-to-face meeting, when the pandemic restrictions loosened. Each focus group interview lasted for one-two hours. All participants signed a consent form approved by the University of Crete Ethics and Deontology Committee and were provided a certificate of participation. National and international research ethics guidelines were followed (Petousi & Sifaki, 2020).

Moreover, each group displayed its characteristics:

- Professional teachers: Professional teachers represented all areas of Crete (urban or rural environments, disadvantaged environments, etc.). There were also representatives from both the Primary and Pre-primary (Preschool) education sector.
- Student-teachers in their final year of studies: These student teachers had completed three teaching practices at schools, so they had already built their experience dealing with curriculum subjects and classroom implementations.
- Parents from a variety of backgrounds.
- STEM professionals, and,
- Artists.

The numbers and a breakdown for each group are displayed in Table 25.1.

Developing teachers' competencies to expand young children's capacity to engage with STEAM demands the engagement of multiple factors and agents (e.g., curricula, policies, Higher Education Institutions, professional development services, etc.). Thus, by addressing a variety of agents, the study becomes more pervasive by

**Table 25.1** The sample of our research

| Sample | Description |
|---|---|
| Teachers | Twenty-four teachers (5 from the primary and 15 from the preschool sector, from rural and urban, advantaged and disadvantaged areas), 3 males and 21 females, with an average teaching experience of ten years |
| Student-teachers | 17 Student-teachers, in their final year, coming from a variety of backgrounds, all females, 23–50 years old (the sample also included a mature student) |
| Stakeholders (parents) | Nine parents from a variety of backgrounds (3 males and 6 females) (occupations: policeman and policewoman, bank clerk, web designer, childcarer, English teacher, engineer, housewife, unemployed) |
| STEAM professionals | Six professionals (4 males and 2 females) (occupations: mathematician, engineers, project manager, physics teacher, biologist) |
| Artists | 2 males and 2 females (occupations: musician, museum educator, actor, writer, painter) |

addressing pre-service and in-service teachers. It also upgrades the issue to address gender stereotypes and include parents, artists, and female STEM professionals.

### 25.3.3 *Questions Asked During the Focus Groups Interviews*

The questions drafted by the NGSS project team and addressed to the different groups during the focus groups interviews can be found in Tables 25.2, 25.3, 25.4 and 25.5.

**Table 25.2** Common questions for all the focus groups

| | Common questions addressed to all groups |
|---|---|
| Q1 | What do you understand from STEM and STEAM? |
| Q2 | What kind of strategies could teachers use to motivate and engage the pupils in science lessons? |
| Q3 | What are the challenges in motivating and engaging girls enough to choose STEM/STEAM activities and courses in pre-primary and primary schools? |

**Table 25.3** Additional questions for teachers and student teachers

| | Additional questions for teachers and student teachers |
|---|---|
| Q1 | What kind of experience did you have with the STEM/STEAM approach; what do you know about STEM/STEAM? |
| Q2 | What difficulties do you face/or could you face in implementing this approach (challenges related to infrastructure, logistics, the framework provided by your national curriculum, the lesson plans design, etc.)? |
| Q3 | How did you overcome these difficulties; which were the strengths that helped you; did you have any support from the policymakers or other stakeholders? |
| Q4 | What are your expectations related to the implementation of STEAM? |
| Q5 | How do you feel about the effects of STEAM teaching on children? |
| Q6 | What kind of strategies could you use to motivate and engage pupils for STEAM lessons? |
| Q7 | Do you think the current stimulation offered in pre-primary & primary schools motivates and engages the girls & disadvantaged groups enough to choose STEM/STEAM courses? |
| Q8 | What do you expect from a pre-primary or primary school to provide you while teaching in a class of girls? |
| Q9 | What kind of training, educational programs, materials, seminars, tools, and platforms do you expect for STEM? |
| Q10 | How well prepared do you feel you are to plan STEM/STEAM lessons for your pupils? |
| Q11 | Do you think you need more training, workshops about STEAM+Arts? Have you received them before? What kind of support do you need to become efficient and motivate your pupils? |
| Q12 | While teaching STEM/science lessons, do you consider their social-emotional learning process and include activities to increase their motivation? |

**Table 25.4** Additional questions for female STEM professionals and artists

| | Additional questions for female STEM professionals and artists |
|---|---|
| Q1 | When you are doing science, do you think you are doing ART? (question for art professionals) |
| Q2 | When creating ART, do you think you are doing science? (question for STEM professionals) |
| Q3 | What kind of methodology do you use to make STEM/STEAM more attractive to girls and disadvantaged students? |
| Q4 | What would you do to help girls and disadvantaged students become familiar with tools and other devices? |

**Table 25.5** Additional questions for parents (of mainstream and disadvantaged pupils)

| | Additional questions for parents (of mainstream and disadvantaged pupils) |
|---|---|
| Q1 | Do you notice any behavioural differences among your children of different genders while learning science, and are there differences in their emotional reactions? |
| Q2 | Do you notice differences among your children of different gender in activities such as watching cartoons, playing with toys, etc.? |
| Q3 | What kind of educational toys do you choose for your children in terms of social and emotional learning? |
| Q4 | Have you ever talked to your children about the value of Science and Art? If so, what topics were the children curious about? |

## 25.4 Results

### *25.4.1 Focus Groups Interview Results*

#### 25.4.1.1 Personal Experience and Knowledge Teachers, Student Teachers, and STEAM Professionals Had with the STEAM Approach

Most teachers, student teachers, and STEAM professionals knew about STEAM, but only a few had the experience of implementing it. In general, all these groups identified themselves as inexperienced in teaching STEM subjects through art and teaching STEM in general. Their understanding of STEAM was that of using art to make teaching more enjoyable and creative for children. A small number of teachers and student teachers mentioned that art could also develop a better understanding of the world and society. Furthermore, art could contribute to the child's socio-emotional and holistic development. STEAM professionals were found to be well informed about STEAM. Student teachers were also more informed than professional teachers about the approach. This can be explained by new teachers having more input about the STEAM approach during their undergraduate studies.

STEAM professionals were found to be aware of the possibility of teaching/approaching science and/or art in an integrated way (trans- and interdisciplinary). However, STEM professionals had a simple idea about STEM–Art integration. Their answers did not show good understanding, as all of them linked art with creativity. On the other hand, artists were more aware that the art they serve is primarily defined by science. Artists displayed the belief that good art demands good science and science can be artistic by itself.

#### 25.4.1.2 Difficulties Faced in Implementing the STEAM Approach (Challenges Related to Infrastructure/Logistics, the Framework Provided by the National Curriculum, the Lesson Plans Design, etc.)

The difficulties reported by the Greek teachers and student teachers can form the following categories (the answers provided by these two groups did not present any significant difference):

- Difficulties in applying the STEAM methodology: Teachers and student teachers reported problems using and developing several attributes of the STEAM approach. They reported difficulty, for example, in initiating children's interest, adjusting to children's level, making STEAM learning experiential. They mentioned problems to ensure safety during experiments and difficulty acting with the flexibility to an unexpected development.
- Lack of knowledge, appropriate training, and experience: Many teachers and student teachers reported that their knowledge and experience limits affected their efforts to deliver STEAM lessons. These hinder them from adopting a flexible inquiry-based and art-based approach.
- Finally, teachers and student teachers identified the lack of resources as a restrictive factor in implementing the STEAM approach. Teachers identified resource shortages as a significant impediment in STEAM delivery. Student teachers referred to their practicum experience and reported resource shortage in the public schools where they practiced their teaching.

#### 25.4.1.3 How Educators Overcame Difficulties; Their Strengths; People Who Helped Them; Support from the Policymakers or Other Stakeholders

None of the teachers or student teachers reported receiving any help from policymakers, stakeholders, advisers, etc. Some teachers and student teachers reported that their interest, personal study, and effort helped them understand and implement STEAM lessons. The practice itself was an effective means of understanding, especially for student teachers. The collaboration with a more experienced teacher or mentor has helped some teachers and student teachers evolve and deliver STEAM content. Finally, both teachers and student teachers mentioned technology and the Internet as a source of education about STEAM.

#### 25.4.1.4 Perceptions of Readiness to Implement the STEAM Approach; Training Needs

Most participants reported that they did not feel quite ready to teach STEAM lessons in their class, especially to implement an art-based approach. However, artistic, and creative activities belong to preschool and school education routines. They all identified their need for further training. Student teachers expressed their wish to have more STEAM lessons in initial training. Some participants identified the need for personal study to increase their knowledge of the subject. Another group concluded that to implement the STEAM approach, they would need careful and thoughtful preparation. When they were asked to identify their training needs, teachers and student teachers mentioned that they need to be offered opportunities for (a) professional development on the use of information platforms and open-source digital materials, (b) mentoring, (c) fieldwork in non-formal education providers such as museums, (d) demonstration lessons and (e) examples of the best teaching approaches. They all mentioned that funding and the provision of resources would enable them to implement successful STEAM lessons. Finally, they mentioned the need for predesigned school projects and lesson plans on STEAM topics. Some teachers and student teachers suggested training on pedagogical content knowledge and the essential STEAM topics and concepts.

#### 25.4.1.5 Expectations Related to Implementing the STEAM Approach; Perceived Characteristics/Attributes of a "Good Practice" in STEAM Education

Regarding their expectations and the attributes of good practice in STEAM, we could group teachers' and student teachers' answers into the following categories:

- It is expected that STEAM will enrich the curriculum and increase STEAM and children's contact with digital environments, and increase children's appreciation of art.
- STEAM will positively impact children's knowledge, both theoretical knowledge and the understanding of everyday life.
- As a learning process, STEAM includes and should result in active and experiential learning with hands-on experimentation and good teamwork. Children can become good inquirers, and art will provide more stimuli and fun, increasing children's interest in STEAM.
- It is also expected that the STEAM approach will help children's socio-emotional development through teamwork. It will also increase children's self-esteem and cultivate children's communication skills.

Some teachers and student teachers realized that the STEAM approach demands and brings changes in their practices and pedagogical attitudes. They mentioned that succeeding in STEAM demands teachers to act less like experts and more like inquirers who are not afraid to make mistakes. Learning with the children was also identified as an attribute of the STEAM approach. Both groups (teachers and student teachers) mentioned this.

#### 25.4.1.6 The Expected Effects of STEAM on Children

Teachers and student teachers could detect the impact of STEAM on the following:

- STEAM is expected to increase the quality of learning: Children are to find learning through STEAM easier, more enjoyable, and active. They are expected to get essential knowledge about the world and learn to use the scientific method of discovery and the extraction of conclusions.
- STEAM is expected to provide opportunities for the development of good communication skills. Through STEAM, children will increase their creativity and learn to appreciate art better.
- Children are to develop better thinking: STEAM is expected to open children's minds and help them to think at different levels. Children can exercise problem-solving and develop critical thinking skills.
- Finally, a better understanding of complex concepts and how the world works is expected to be achieved.

#### 25.4.1.7 Are children's Social and Emotional Learning Processes Taken into Account in STEAM or Science Lessons?

All teachers and student teachers claimed that they took children's social and emotional learning into account. Some could explain this further and show a good understanding of this issue. For example, participants said that allowing students to present findings and express themselves positively impacted their self-esteem and self-confidence. They also said that art enables children to discover multiple perspectives and develop empathy. It also provides communication pathways for children with language issues (e.g., immigrant and refugee children). In general, participants understood how STEAM could promote social and emotional learning. They could also explain how an open and child-centered methodology contributes to children's healthy social and emotional development. Not all teachers and student teachers seem to recognize how STEAM can contribute to social and emotional learning. On the contrary, they could not acknowledge that social and emotional learning is crucial in successful STEAM lessons.

#### 25.4.1.8 The Participant's Perception of the Value of STEAM in Increasing the Motivation and Participation of Young Girls in STEM Fields of Study and Careers

Teachers and student teachers did refer to the professional perspectives STEAM lessons offer to children. They believe that STEAM prepares children for choosing a profession in the future.

#### 25.4.1.9 How Did the STEAM Professional Make STEM/STEAM More Attractive to Girls and Disadvantaged Students?

STEAM professionals mentioned that it is best to start with simple tasks and then advance at more complicated stages when working on a STEAM topic. They also suggested resorting to children's interests. Moreover, they highlighted that ICT provides good help towards attaining learning targets, which can benefit disadvantaged students.

#### 25.4.1.10 Do Parents Have Biased Perceptions of Gender Differences in the Use of Toys, Programs, and Activities?

Parents did not picture gender differences in their children's behavior, learning, and preferences. Although they all claimed that both genders show the same interest in STEAM subjects nowadays, they simultaneously recognized differences in boys' and girls' choices. However, most of them concluded that this could probably be due to children's stereotypical behaviors and parochial ideas passed on to them by their environment.

#### 25.4.1.11 Parents' Perceptions of Science and Art

Parents understood the difference between STEAM and STEAM mainly in terms of creativity. Greek parents do not have much knowledge or experience on the subject as this was recently introduced to the school reality in Greece. Therefore, they tried to imagine what the difference would be. They concluded that art would enable children to express their ideas better and bear innovative ideas.

## 25.5 Discussion

The general outcome was that people (teachers, prospective teachers, parents, professionals) might be very excited about integrating Art with STEM subjects. However, they might not quite understand the real reasons and benefits of this. They do not realize the potential of deeper understanding and holistic development the STEAM approach offers. Other research studies also showed that, despite the general enthusiasm, STEAM lesson implementation remained low, and the understanding of STEAM was limited (DeJarnette, 2018; Diana et al., 2021). In addition, research detects pre-service teachers' limited knowledge of methodological techniques (Kim et al., 2020).

Moreover, teachers and student teachers might understand that the STEAM approach is part and parcel of a constructivist teaching and learning methodology. In this methodology, children are frequently encouraged to take the lead. However, they show that they do not feel knowledgeable or confident enough to change their old practices. Almost all of them stressed the need for training. Very few realized that they also needed to work harder to include new methodologies into a routine. The above findings agree with another study carried out in the Greek territory focusing on the teachers' perspectives on the importance of STEM in Greek Preschool Education. Baltsavias and Kyridis (2020) also found that Greek preschool teachers are willing to receive further training and emphasize the STEAM approach. However, they do not apply the STEM approach with its emphasis on hands-on learning and interdisciplinarity. They focus mainly on Mathematics, neglecting or paying less attention to the other STEM subjects. Other studies highlight the vital role of efficient training (see, indicatively, Conradty & Bogner, 2020; DeJarnette, 2018).

Another major conclusion was that both professional and perspective teachers feel that the STEAM approach needs bolder support in curriculum guides, lesson plans, materials, and educational resources. Frequently, this lack of support makes it impossible to deliver the STEAM goals, no matter how enthusiastic the teachers are. These needs are brought up and highlighted by other studies (Bahrum et al., 2017; DeJarnette, 2018; Hawari & Noor, 2020; Lee & Shin, 2014).

The development of the social-emotional aspects of learning seems to have teachers' attention in this study. Teachers do recognize how disadvantaged students might come across many difficulties in succeeding in STEM. A more thorough investigation is needed in the development of further actions. Research reveals that the social-emotional elements seem to be essential factors influencing participation and achievement in STEM subjects (Niu, 2017; Xie et al., 2015). This is particularly important for teachers of young children. Research has shown that STEAM teachers pay more attention to developing children's soft skills, which does not promote STEAM abilities (Monkeviciene et al., 2020).

It is also notable that, in this study, neither the teachers (professionals and student teachers) nor the parents recognized that there is female underachievement in STEM subjects and STEM careers. One possible explanation is that teachers and parents are not aware of the girls' underachievement in STEM subjects. Thus, they deny that this is so. In other words, they might not inform teachers and parents, and they ignore the differences. According to another explanation, teachers and parents are misled by the excellent performance of girls in mathematics and science at the primary level (see UNICEF, 2020). They are not also aware of how this develops at a later stage. UNICEF (2020) highlights that "girls are less likely than boys to achieve high proficiency levels in STEM" (p. 7), and "fewer girls than boys aspire to careers in science, technology or engineering, even among top performers" (p. 13). In either case, there is a need for further investigation into this matter. Other studies reveal that teachers and parents are not always aware of their gender-biased perceptions (Åhslund & Boström, 2018; Freeman, 2007; Ghosh, 2004; Riegle-Crumb et al., 2012; Šimunović & Babarović, 2020; Tatar & Emmanuel, 2001). Overall, the research identifies the need for further investigation into the factors that affect teachers' and parents' perceptions.

The present study sample is not representative, although the selection process attempted to include many participants. Thus, the above findings cannot be generated, or be considered to give an accurate picture of the current situation and practices in Greek Preschool Education. Further investigation into a larger sample is needed so that they can draw safer conclusions. In addition, research should focus on each group separately (professional teachers, student teachers, parents, STEM professionals, artists). This will reveal the perceptions and needs of each group in more detail. However, the present study identified issues identified by the international literature. It also indicates that STEAM education in Greece faces similar challenges and needs regarding the teachers' training and support and people's perceptions. Gender differences and the support of disadvantaged students also need to be taken into further consideration.

## 25.6 Conclusion

STEM subjects can be challenging for young children. Due to particular developmental characteristics, it might prove difficult for young children to understand or change the misconceptions about physical phenomena or grasp the meaning of scientific information presented to them. Moreover, Art needs to come to the forefront and methodologically cannot be limited to support another subject. Besides, "teachers are less concerned about theoretical models and more interested in how art can be featured in the curriculum in addition to being used as an instructional tool to enhance STEM lessons in a practical manner" (Kuhn et al., 2016, p. 10). The STEAM approach supports and boosts all students' achievement and inclusion and helps develop positive attitudes towards future STEM careers (Caton, 2021; Conradty et al., 2020).

There are formal and informal ways to involve students' parents or teachers in STEM education (Peterson, 2017). Researchers, stakeholders, policymakers must help educators and parents encourage STEAM learning at school and home and help their students' critical thinking (McClure et al., 2017). However, STEAM implementation is a multifaceted matter which demands researchers and trainers to focus on and systematically explore its dimensions to achieve a more significant integral impact on children through the professional development of their teachers.

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**Conflict of Interest** The authors declare they researched without any commercial or financial relationships construed as a potential conflict of interest.

**Data Availability Statement** The raw data supporting the conclusions of this article will be made available by the authors without undue resorts.

**ICS Statement** The study was conducted according to the guidelines of the Declaration of Helsinki. The Ethics Committee of the Department of Preschool Education of the University of Crete, Greece, and the Ethics and Deontology Committee of the University of Crete, Greece, also approved it.

## References

Åhslund, I., & Boström, L. (2018). Teachers' perceptions of gender differences—What about boys and girls in the classroom? *International Journal of Learning, Teaching and Educational Research, 17*(4), 28–44. https://doi.org/10.26803/ijlter.17.4.2

Akiri, E., Tor, H. M., & Dori, Y. J. (2021). Teaching and assessment methods: STEM teachers' perceptions and implementation. *Eurasia Journal of Mathematics, Science and Technology Education, 17*(6). https://doi.org/10.29333/ejmste/10882

Aldemir, J., & Kermani, H. (2017). Integrated STEM curriculum: Improving educational outcomes for Head Start children. *Early Child Development & Care, 187*(11), 1694–1706. https://doi.org/10.1080/03004430.2016.1185102

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences, 11*(7), 331.

Bagiati, A., & Evangelou, D. (2015). Engineering curriculum in the preschool classroom: The teacher's experience. *European Early Childhood Education Research Journal, 23*(1), 112–128. https://doi.org/10.1080/1350293X.2014.991099

Bahrum, S., Wahid, N., & Ibrahim, N. (2017). STEM integration module in teaching and learning with visual arts education: A needs of analysis. *International Journal of Academic Research in Business and Social Sciences, 7*(2), 582–590.

Baltsavias, A., & Kyridis, A. (2020). Preschool teachers' perspectives on the importance of STEM education in Greek preschool education. *Journal of Education and Practice, 11*(14).

Barnes, J., FakhrHosseini, S. M., Vasey, E., Park, C. H., & Jeon, M. (2020). Child-robot theater: Engaging elementary students in informal STEAM education using robots. *IEEE Pervasive Computing, 19*(1), 22–31.

Bartels, S. L., Rupe, K. M., & Lederman, J. S. (2019). Shaping preservice teachers' understandings of STEM: A collaborative math and science methods approach. *Journal of Science Teacher Education, 30*(6), 666–680.

Berisha, F., & Vula, E. (2021). Developing preservice teachers STEM understanding and pedagogical practices. *Frontiers in Education, 6*, 142. https://doi.org/10.3389/feduc.2021.585075

Bissaker, K. (2014). Transforming STEM education in an innovative Australian school: The role of teachers' and academics' professional partnerships. *Theory into Practice, 53*, 55–63. https://doi.org/10.1080/00405841.2014.862124

Blotnicky, K. A., Franz-Odendaal, T., French, F., & Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. *International Journal of STEM Education, 5*(1). https://doi.org/10.1186/s40594-018-0118-3

Botella, C., Rueda, S., López-Iñesta, E., & Marzal, P. (2019). Gender diversity in STEM disciplines: A multiple factor problem. *Entropy*, *21*(1). https://doi.org/10.3390/e21010030

Catchen, R. (2013). Reflections—How STEM becomes STEAM. *The STEAM Journal, 1*(1), 1–4. https://doi.org/10.5642/steam.201301.22

Caton, J. (2021). Don't run out of STEAM! Barriers to a transdisciplinary learning approach. *Journal of STEM Teacher Education, 56*(1), 38–45. https://doi.org/10.30707/jste56.1.1624981200.219832

Church, A., & Cohrssen, C. (2021). The mechanics of interaction in early childhood STEAM. In *Embedding STEAM in early childhood education and care* (pp. 217–236). Palgrave Macmillan.

Cohrssen, C., & Page, J. (2016). Articulating a rights-based argument for mathematics teaching and learning in early childhood education. *Australasian Journal of Early Childhood, 41*(3), 104–108.

Committee on STEM Education of the National Science and Technology Council. (2018). *Charting a course for success: America's strategy for STEM education*. The White House.

Conradty, C., & Bogner, F. X. (2020). STEAM teaching professional development works: Effects on students' creativity and motivation. *Smart Learning Environments, 7*(1), 1–20.

Conradty, C., & Bogner, F. X. (2019). From STEM to STEAM: Cracking the code? How creativity & motivation interacts with inquiry-based learning. *Creativity Research Journal, 31*(3), 284–295.

Conradty, C., Sotiriou, S. A., & Bogner, F. X. (2020). How creativity in STEAM modules intervenes with self-efficacy and motivation. *Education Sciences, 10*(3), 70. https://doi.org/10.3390/educsci10030070

Dasgupta, N., & Stout, J. G. (2014). Girls and women in science, technology, engineering, and mathematics: Stemming the tide and broadening participation in STEM careers. *Policy Insights from the Behavioral and Brain Sciences, 1*(1), 21–29.

Dee, T., & Gershenson, S. (2017). *Unconscious bias in the classroom: Evidence and opportunities*. Google. Retrieved August 23, 2021 from https://goo.gl/O6Btqi

DeJarnette, N. K. (2018). Implementing STEAM in the early childhood classroom. *European Journal of STEM Education, 3*(3), 18. https://doi.org/10.20897/ejsteme/3878

Diana, N., Turmudi, & Yohannes. (2021). Analysis of teachers' difficulties in implementing STEM approach in learning: A study literature. *Journal of Physics: Conference Series*, *1806*(1). https://doi.org/10.1088/1742-6596/1806/1/012219

Ejiwale, J. A. (2013). Barriers to successful implementation of STEM education. *Journal of Education and Learning (EduLearn), 7*(2), 63–74. https://doi.org/10.11591/EDULEARN.V7I2.220

European Centre for the Development of Vocational Training. (2016). *Skill shortages in Europe. Which occupations are in demand—And why*. Press Release. Retrieved August 30, 2021 from https://www.cedefop.europa.eu/en/news-and-press/news/skill-shortages-europe-which-occupations-are-demand-and-why

Freeman, N. K. (2007). Preschoolers' perceptions of gender-appropriate toys and their parents' beliefs about genderized behaviors: Miscommunication, mixed messages, or hidden truths? *Early Childhood Education Journal, 34*(5), 357–366. https://doi.org/10.1007/s10643-006-0123-x

Ghosh, S. (2004). *Teachers' beliefs on gender differences in mathematics education* (Ph.D. Thesis). Florida State University Libraries, ProQuest Dissertations Publishing.

Glaser, B. G. (2016). Open coding descriptions. *Grounded Theory Review: an International Journal, 15*(2), 108–110.

Glennie, E., Mason, M., Dalton, B., & Edmunds, J. (2019). Preparing students for STEM college and careers. *The High School Journal, 102*(3), 228–257.

Hachey, A. C. (2020). Success for all: Fostering early childhood STEM identity. *Journal of Research in Innovative Teaching & Learning, 13*(1), 135–139.

Hammack, R., & Ivey, T. (2019). Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation. *Journal of Engineering Education, 108*(4), 503–522. https://doi.org/10.1002/jee.20289

Harlow, D. B., Hansen, A. K., McBeath, J. K., & Leak, A. E. (2018). Teacher education for maker education: Helping teachers develop appropriate PCK for engaging children in educative making. In S. M. Uzzo, S. B. Graves, E. Shay, M. Harford, & R. Thompson (Eds.), *Pedagogical content knowledge in stem* (pp. 265–280). Springer. https://doi.org/10.1007/978-3-319-97475-0_14

Hawari, A. D. M., & Noor, A. I. M. (2020). Project-based learning pedagogical design in STEAM art education. *Asian Journal of University Education, 16*(3), 102–111. https://doi.org/10.24191/ajue.v16i3.11072

Hedlin, M., & Gunnarsson, G. (2014). Preschool student teachers, technology, and gender: Positive expectations despite mixed experiences from their own school days. *Early Child Development and Care, 184*(12), 1948–1959.

Henriksen, D. (2014). Full STEAM ahead: Creativity in excellent STEM teaching practices. *The STEAM Journal, 1*(2), 1–9. https://doi.org/10.5642/steam.20140102.15

Jamil, F. M., Linder, S. M., & Stegelin, D. A. (2018). Early childhood teacher beliefs about STEAM education after a professional development conference. *Early Childhood Education Journal, 46*(4), 409–417. https://doi.org/10.1007/s10643-017-0875-5

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*, 11. https://doi.org/10.1186/s40594-016-0046-z

Kennedy, T., & Odell, M. (2014). Engaging students in STEM education. *Science Education International, 25*, 246–258.

Kim, J. Y., Chung, H., Young Jung, E., Kim, J. O., & Lee, T. W. (2020). Development and application of a novel engineering-based maker education course for pre-service teachers. *Education Sciences, 10*(5). https://doi.org/10.3390/educsci10050126

Kuhn, M. A., Greenhalgh, S., & McDermott, M. (2016). Using creativity from art and engineering to engage students in science. *Journal of STEM Arts, Crafts, and Constructions, 1*(2), 2.

Kumar, R. (2016). Working with families to inspire children's persistence in STEM. *Childhood Education, 92*(5), 358–364. https://doi.org/10.1080/00094056.2016.1226108

Land, M. (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. *Procedia Computer Science, 20*, 547–552. https://doi.org/10.1016/j.procs.2013.09.317

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*, 681–718. https://doi.org/10.3102/0034654315627366

Lee, J.-M., & Shin, Y.-J. (2014). An analysis of elementary school teachers' difficulties in the STEAM class. *Elementary Science Education, 33*(3), 588–596. https://doi.org/10.15267/keses.2014.33.3.588

Lochmiller, C. R. (2021). Conducting thematic analysis with qualitative data. *Qualitative Report, 26*(6), 2029–2044. https://doi.org/10.46743/2160-3715/2021.5008

MacDonald, A., Huser, C., Sikder, S., & Danaia, L. (2020). Effective early childhood STEM education: Findings from the *Little Scientists* evaluation. *Early Childhood Education Journal, 48*, 353–363.

Maris, S., Maris, S. A., Cojocariu, N., & Humita, M. (2018). Using ICT support for STEM education in disadvantaged youth learning. In *2018 13th International Symposium on Electronics and Telecommunications, ISETC 2018—Conference Proceedings*, 1–4. https://doi.org/10.1109/ISETC.2018.8583873

Matsagouras, H. (2012). *Interdisciplinarity in school knowledge*. Grigori. (in Greek).

McClure, E. R., Guernsey, L., Clements, D. H., Bales, S. N., Nichols, J., Kendall-Taylor, N., & Levine, M. H. (2017). STEM starts early: Grounding science, technology, engineering, and math education in early childhood. In *Joan Ganz Cooney Center at Sesame Workshop*, 1900 Broadway, New York, NY 10023.

McGuire, L., Mulvey, K. L., Goff, E., Irvin, M. J., Winterbottom, M., Fields, G. E., Hartstone-Rose, A., & Rutland, A. (2020). STEM gender stereotypes from early childhood through adolescence at informal science centers. *Journal of Applied Developmental Psychology, 67*, 101–109. https://doi.org/10.1016/j.appdev.2020.101109

Means, B., Wang, H., Wei, X., Young, V., & Iwatani, E. (2021). Impacts of attending an inclusive STEM high school: Meta-analytic estimates from five studies. *International Journal of STEM Education, 8*(4). https://doi.org/10.1186/s40594-020-00260-1

Milner-Bolotin, M. (2018). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in Education, 3*(92). https://doi.org/10.3389/feduc.2018.00092

Monkeviciene, O., Autukeviciene, B., Kaminskiene, L., & Monkevicius, J. (2020). Impact of innovative steam education practices on teacher professional development and 3-6-year-old children's competence development. *Journal of Social Studies Education Research, 11*(4), 1–27.

Moomaw, S., & Davis, J. A. (2010). STEM comes to preschool. *YC Young Children*, *65*(5), 12–14, 16–8.

Morrison, J., & Bartlett, B. (2009). STEM as curriculum: An experimental approach. *Education Week, 8*(23), 28–31.

Niu, L. (2017). Family socioeconomic status and choice of STEM major in college: An analysis of a national sample. *College Student Journal, 51*(2), 218–315.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1–13. https://doi.org/10.1177/1609406917733847

O'Leary, E. S., Shapiro, C., Toma, S., Sayson, H. W., Levis-Fitzgerald, M., Johnson, T., & Sork, V. L. (2020). Creating inclusive classrooms by engaging STEM faculty in culturally responsive teaching workshops. *International Journal of STEM Education, 7*(1), 32. https://doi.org/10.1186/s40594-020-00230-7

O'Nyumba, T., Wilson, K., Derrick, C. J., & Mukherjee, N. (2018). The use of focus group discussion methodology: Insights from two decades of application in conservation. *Methods in Ecology and Evolution, 9*(1), 20–32. https://doi.org/10.1111/2041-210X.12860

Panizzon, D., & Westwell, M. (2009). *Engaging students in STEM-related subjects: What does the research evidence say?* Retrieved August 2, 2017 from http://www.flinders.edu.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=A5917489-C8D7-01A1-D537-13FFAA534FEB&siteName=flinders

Park, H., Byun, S. Y., Sim, J., Han, H. S., & Baek, Y. S. (2016). Teachers' perceptions and practices of STEAM education in South Korea. *Eurasia Journal of Mathematics, Science and Technology Education, 12*(7), 1739–1753.

Park, M.-H., Dimitrov, D. M., Patterson, L. G., & Park, D.-Y. (2017). Early childhood teachers' beliefs about readiness for teaching science, technology, engineering, and mathematics. *Journal of Early Childhood Research, 15*(3), 275–291. https://doi.org/10.1177/1476718X15614040

Patrick, H., Mantzicopoulos, P., & Samarapungavan, A. (2009). Motivation for learning science in Kindergarten: Is there a gender gap and does integrated inquiry and literacy instruction make a difference. *Journal of Research in Science Teaching, 46*(2), 166–191.

Peterson, B. (2017). Engaging parents in STEM education. *Children's Technology and Engineering, 22*(1), 18–21.

Petousi, V., & Sifaki, E. (2020). Contextualizing harm in the framework of research misconduct. Findings from discourse analysis of scientific publications. *International Journal of Sustainable Development, 23*(3/4), 149–174.

Pimthong, P., & Williams, P. J. (2021). Methods course for primary level STEM pre-service teachers: Constructing integrated STEM teaching. *EURASIA Journal of Mathematics, Science and Technology Education, 17*(8).

Ramsey, K., & Baethe, B. (2013). The keys to future STEM careers: Basic skills, critical thinking, and ethics. *Delta Kappa Gamma Bulletin, 80*(1), 26.

Riegle-Crumb, C., King, B., Grodsky, E., & Muller, C. (2012). The more things change, the more they stay the same? prior achievement fails to explain gender inequality in entry into STEM college majors over time. *American Educational Research Journal, 49*(6), 1048–1073. https://doi.org/10.3102/0002831211435229

Salvaras, G. (2004). Interdisciplinarity, interdisciplinarity in curricula: Theoretical consideration and foundation, in the collective volume. *Interdisciplinarity and education* (pp. 129–157). Patakis.

Sanders, M. E. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, *68*(4), 20–26.

Scinski, L. (2014). *Beyond the classroom: The impact of informal STEM experiences on student attitudes and interest*. UC San Diego. ProQuest ID: Scinski_ucsd_0033D_14488.

Shapiro, J. R., & Williams, A. M. (2012). The role of stereotype threats in undermining girls' and women's performance and interest in STEM fields. *Sex Roles, 66*(3–4), 175–183.

Sim, J., & Waterfield, J. (2019). Focus group methodology: Some ethical challenges. *Quality and Quantity, 53*(6), 3003–3022. https://doi.org/10.1007/s11135-019-00914-5

Šimunović, M., & Babarović, T. (2020). The role of parents' beliefs in students' motivation, achievement, and choices in the STEM domain: A review and directions for future research. *Social Psychology of Education, 23*(3), 701–719. https://doi.org/10.1007/s11218-020-09555-1

Slavit, D., Nelson, T. H., & Lesseig, K. (2016). The teachers' role in developing, opening, and nurturing an inclusive STEM-focused school. *International Journal of STEM Education, 3*(1), 7. https://doi.org/10.1186/s40594-016-0040-5

Subotnik, R. F., Stoeger, H., & Luo, L. (2019). Exploring compensations for demographic disadvantage in science talent development. *New Directions for Child and Adolescent Development*, (168), 101–130. https://doi.org/10.1002/cad.20321

Sullivan, A., & Strawhacker, A. (2021). Screen-free STEAM: Low-cost and hands-on approaches to teaching coding and engineering to young children. In *Embedding STEAM in early childhood education and care* (pp. 87–113). Palgrave Macmillan.

Tatar, M., & Emmanuel, G. (2001). Teachers' perceptions of their students' gender roles. *Journal of Educational Research, 94*(4). https://doi.org/10.1080/00220670109598755

Tippett, C. D., & Milford, T. M. (2017). Findings from a pre-kindergarten classroom: Making the case for STEM in early childhood education. *International Journal of Science and Mathematics Education, 15*, 67–86.

United Nations Children's Fund (UNICEF). (2020). *Mapping gender equality in STEM from school to work. A journey in 17 charts.* Office of Global Insight & Policy.

United Nations Children's Fund (UNICEF) & International Telecommunication Union (ITU). (2020). *Towards an equal future: Reimagining girls' education through STEM*. UNICEF Education Section.

Vahey, P., Vidiksis, R., & Adair, A. (2019). Science literacy in early childhood: The connection between home and school. *American Educator, 42*(4), 17–21, 40.

Vaismoradi, M., & Snelgrove, S. (2019). Theme in qualitative content analysis and thematic analysis. *Forum Qualitative Sozialforschung, 20*(3). https://doi.org/10.17169/fqs-20.3.3376

van Keulen, H. (2018). STEM in early childhood education. *European Journal of STEM Education, 3*(3), 06. https://doi.org/10.20897/ejsteme/3866

Wang, M. T., & Degol, J. L. (2017). Gender gap in Science, Technology, Engineering, and Mathematics (STEM): Current knowledge, implications for practice, policy, and future directions. *Educational Psychology Review, 29*(1), 119–140.

Winangun, M. M., & Fauziah, D. (2019). Designing lesson plan of Science, Technology, Engineering, Mathematics (STEM) education in science learning. *Journal of Physics: Conference Series, 1318*(1). https://doi.org/10.1088/1742-6596/1318/1/012024

White, D. W. (2014). What is STEM education and why is it important? *Florida Association of Teacher Educators Journal, 1*(14), 1–8.

Xie, Y., Fang, M., & Shauman, K. (2015). Stem Education. *Annual Review of Sociology*, *41*, 331–357. https://dx.doi.org/10.1146/annurev-soc-071312-145659