Contemporary Issues in Technology Education

P. John Williams
Belinda von Mengersen *Editors*

Applications of Research in Technology Education

Helping Teachers Develop Research-Informed Practice

Springer

Contemporary Issues in Technology Education

Series Editors

P. John Williams, Curtin University, Perth, WA, Australia

Marc J. de Vries, Technische Universiteit Delft, Delft, The Netherlands

Technology education is a developing field, new issues keep arising and timely, relevant research is continually being conducted. The aim of this series is to draw on the latest research to focus on contemporary issues, create debate and push the boundaries in order to expand the field of technology education and explore new paradigms. Maybe more than any other subject, technology education has strong links with other learning areas, including the humanities and the sciences, and exploring these boundaries and the gaps between them will be a focus of this series. Much of the literature from other disciplines has applicability to technology education, and harnessing this diversity of research and ideas with a focus on technology will strengthen the field.

Occasional volumes on a bi-annual basis will be published under the Council for Technology and Engineering Teacher Education (CTETE) inside this series.

For more information, or to submit a proposal, please email Grace Ma: grace.ma@springer.com

More information about this series at https://link.springer.com/bookseries/13336

P. John Williams · Belinda von Mengersen
Editors

Applications of Research in Technology Education

Helping Teachers Develop Research-Informed Practice

Springer

Editors
P. John Williams
Curtin University
Perth, WA, Australia

Belinda von Mengersen
Australian Catholic University
Strathfield, NSW, Australia

ISSN 2510-0327 ISSN 2510-0335 (electronic)
Contemporary Issues in Technology Education
ISBN 978-981-16-7884-4 ISBN 978-981-16-7885-1 (eBook)
https://doi.org/10.1007/978-981-16-7885-1

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

Editors and Contributors

About the Editors

P. John Williams He is a Professor of Education and the Director of Graduate Research in the School of Education at Curtin University in Perth, Western Australia, where he teaches and supervises research students in STEM and technology education. Apart from Australia, he has worked and studied in a number of African and Indian Ocean countries and in New Zealand and the United States. His current research interests include STEM, mentoring beginning teachers, PCK and electronic assessment of performance. He regularly presents at international and national conferences, consults on Technology Education in a number of countries, and is a longstanding member of eight professional associations. He is the series editor of Springer's *Contemporary Issues in Technology Education* series and is on the editorial board of six professional journals. He has authored or contributed to over 250 publications, and is elected to the International Technology and Engineering Education Association's Academy of Fellows for prominence in the profession.

Belinda von Mengersen She is a specialist in traditional, current and emerging textile technologies, and leads Design and Technologies at the National School of Arts, Australian Catholic University. She has authored chapters in three volumes of Springer's *Contemporary Issues in Technology* series, regularly reviews articles for the *International Journal of Technology and Design Education* and presents frequently at International Design and Technologies conferences including PATT, TERC and DAATArc. Belinda focuses on reflective, creative and speculative writing in design practice, practice-led research in design, the intersection between signature pedagogies of visual arts, design and technology, and the dynamic and interdisciplinary nature of design-related fields.

Contributors

Piet Ankiewicz University of Johannesburg, Johannesburg, South Africa

Chandan Boodhoo Mauritius Institute of Education, Reduit, Mauritius

Jeffrey Buckley KTH Royal Institute of Technology, Stockholm, Sweden; Technological University of the Shannon: Midlands Midwest, Westmeath, Ireland

Donal Canty University of Limerick, Limerick, Ireland

Anita S. Deck International Technology and Engineering Educators Association, Concord University, Athens, USA

Andrew Doyle KTH Royal Institute of Technology, Stockholm, Sweden; Exeter College, Exeter, England

Lena Gumaelius KTH Royal Institute of Technology, Stockholm, Sweden; Mälardalens Högskola, Västerås, Sweden

Mishack T. Gumbo University of South Africa, Pretoria, South Africa

Neshane Harvey University of Johannesburg, Johannesburg, South Africa

Dawne Irving-Bell Edge Hill University, Ormskirk, UK

P. John Williams Curtin University, Bently, WA, Australia

Todd R. Kelley Purdue University, West Lafayette, USA

Richard Maluleke Nkone Maruping Primary School, Johannesburg, South Africa

Paul Kinyanjui Mburu Roehampton University, London, UK

Nthoesele Mohlomi National Curriculum Development Centre (NCDC), Maseru, Lesotho

Anna Otterborn Science and Technology, Örebro University, Örebro, Sweden

Elizabeth Reinsfield University of Waikato, Hamilton, New Zealand

Konrad Schönborn Media and Information Technology, Linköping University, Linköping, Sweden

Niall Seery Technological University of the Shannon: Midlands Midwest, Westmeath, Ireland

Susheela Shanta Governor's STEM Academy at BCAT in Roanoke County Schools, Charlotte, USA

Pernilla Sundqvist Division of Mathematics and Natural Sciences Didactics, School of Education, Culture and Communication, Mälardalen University, Västerås, Sweden

Euisuk Sung New York City College of Technology, New York, USA

Dave van Breukelen Fontys University of Applied Sciences for Teacher Education Sittard, Eindhoven, the Netherlands

Belinda von Mengersen Australian Catholic University, Strathfield, NSW, Australia

Part I
Introduction

Chapter 1
Developing Research Informed Practice

P. John Williams and Belinda von Mengersen

The goal of this book is to bring together significant international research in Technology Education by focussing on contemporary Ph.D. theses. An international search was conducted through professional associations and higher education institutions, which support postgraduate technology education research, to identify doctoral researchers who have recently completed their theses. Those that were available to develop their thesis into a book chapter constitute the authors in this volume. Of course this is therefore not a representative sample of international research in technology education, but a snapshot of doctoral research from around the world that was concluded in 2019.

There is often a disconnection between higher degree research, which has useful implications for teachers' practice, and sharing this research with teachers. One of the goals of this book is to bridge this disconnection by having researchers focus on the curriculum and pedagogical implications of their research and providing it in this book format which is available to teachers and educators more broadly.

Each author was asked to write a chapter based on their thesis. Each chapter has a similar heading structure, with the focus being on what the research means for classroom teachers. In order to be confident in the conclusions and recommendations that have been outlined in each chapter, a little about the conduct of the research has been included—what were the research questions, how were they answered and how was the data collected and analysed. However, the focus of each chapter is an elaboration of the findings in ways that are relevant for practitioners. Each chapter

P. J. Williams (✉)
Curtin University, Perth, Australia
e-mail: pjohn.williams@curtin.edu.au

B. von Mengersen
Australian Catholic University, Strathfield, Australia
e-mail: belinda.vonmengersen@acu.edu

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_1

provides a reference for the thesis so a reader can pursue more detail if they would like.

The focus of the book is on the provision of evidence informed practice, and we hope this will be useful in two ways. In the implementation of these ideas into their own practice, teachers and educators can be confident that there is a researched rationale underpinning the ideas. Secondly, it can be difficult for teachers to convince school administrators of certain needs in the Technology Education learning area; these chapters provide evidence that may be useful in this context to help ensure that Technology Education is an effective and essential element of the core curriculum.

The chapters have been grouped into three areas:

- perceptions and practices,
- skills in designing,
- curriculum and pedagogy.

1.1 Perceptions and Practices

The four chapters in this section explore the perceptions and practices of leaders, pre-service teachers and practicing teachers towards elements of Technology Education. The research was conducted by Paul Mburu and Dawne Irving-Bell in England, Liz Reinsfield in New Zealand and Andrew Doyle in Ireland.

Paul Mburu examined Design and Technology subject leaders' perceptions through the lens of Cultural Historical Activity Theory (CHAT). Previous research in school subject departments has shown that subject leaders play a vital role in setting the direction and determining the success of their departments, but little has been written in the literature about how Design and Technology secondary school subject department leaders perceive their practices. Paul's analysis of the data he collected can be summarized into three themes. The first is the monitoring of teaching and learning that is conducted within the department. This was done through the mechanisms of visits to colleagues' classrooms, lesson observations and book reviews. Lesson observations were used to confirm good practice and identify areas of further development needed within the department. Student book reviews were a demanding activity but an opportunity to share good practice within the department.

The second theme was building relationships, which subject leaders develop in different ways through informal conversations and more formal department meetings, but contextualized to the needs of the department. The final theme was showcasing and promoting Design and Technology through a broad range of activities: parents' workshops, options evening, taster lessons, parents' workshops, displays and exhibitions.

Through the analysis of CHAT, the activity can be explored by considering how subject leaders interpret the *object* of the activity. The *object* of the activity is the physical or mental product that is sought with the object being acted on by the *subject*. *Subjects*, for example, subject leaders of Design and Technology in this research, do not act on the *object* (for example, working to build collective team learning) directly, their actions are mediated by tools, and it is the tools that transform the object. Thus, by means of *tools* (for example, learning walks, lesson observations, book reviews, etc.) *subjects* in the activity of sustaining and developing Design and Technology in the school curriculum work on the object of the activity.

Dawne Irving-Bell researched the perceptions of pre-service teachers, and how such perceptions are shaped by their previous experiences, and in turn shape their development as teachers. A significant theme which developed from the analysis was related to subject knowledge, and the perception that where a teacher lacks adequate subject knowledge, they are likely to spend their time filling their subject knowledge gaps, rather than focussing on effective ways to deliver knowledge to learners.

An additional outcome of inadequate subject knowledge was the likelihood that in spending their time filling their subject knowledge gaps, teachers would utilize poor pedagogical practices rather than focussing on effective ways to deliver knowledge to learners. These teachers would be more inclined to deliver lessons which were procedural and reliant on pupils following rules, sticking to simple activities, teacher-led lessons and textbook work.

Dawne argues that at the liminal moment when subject matter should become PCK (Pedagogical Content Knowledge), if the pre-service teacher's subject knowledge is deficient (perceived or real), this creates a '*gap*' in the space where one's identity as a teacher is formed, which has the potential to limit personal development and subsequently restrict the formation of the teacher's professional identity.

In cases where a pre-service teacher is not provided the opportunity or is unable to challenge their own experience-formed beliefs, self-sabotaging behaviours may develop. Dawne found that this may result from personal philosophy, ideology or opinions of how a teacher should be, act or behave which are naïve or unrealistic, and opportunities for constant negotiation between one's own ideology, personal philosophy and the reality of professional practice must be provided.

In the next chapter in this section, Liz Reinsfield explored New Zealand teachers' perceptions regarding their curriculum practice and found a disparity between some teachers' perceptions of the nature of Technology Education and their emerging practice. Liz identified persistent tensions that influence technology teachers' pedagogical practice, which include a propensity for some teachers to emphasize practical skills and knowledge over the development of students' creative or critical thinking for the development of innovative outcomes.

All the participants in Liz's research acknowledged the meaning-making processes that were required to interpret the curriculum to then apply their understandings in practice. As with Dawne in the previous chapter, Liz identified this liminal space through which teachers must proceed in engaging with a concept, and thereby making personal meaning and developing the ability to apply the concept in different contexts.

Teachers' objectives for learning were affected by their perceptions about the nature of the subject, the social, cultural, political and economic discourse in which they practice, as well as what is legitimate knowledge. The data indicated teachers' intentions to consolidate their understanding of the technology curriculum in their school with a view to improve their classroom-based practice. Participants highlighted this could be done by affirming their current understandings, identifying some goals for their future practice, through the integration of curriculum knowledge, as well as through pedagogical risk-taking.

The teachers' understanding was connected to their experience of teaching technology, their engagement with the curriculum and the school-based circumstances that were mediating their practice. The findings suggested that there were pervasive and historically based assumptions about the nature of technology education which influenced teacher's practice. Fortunately, the data also indicated that if technology teachers were motivated to challenge others' thinking, engage in dialogue about the subject and how it is enacted in the classroom, and support the community's developing understandings, these assumptions could be reconceived.

In the final chapter in this section, and closely related to Liz's chapter, Andrew Doyle focusses on the dissonance between technology education rhetoric and teacher's practice. The rhetoric includes technological capability and technological literacy as dominant, however technological perspective, technological competence and technacy are also used to describe intended learning outcomes. These constructs are often used to describe learning outcomes in a space where the specific subject matter is elusive, but they are, by their very nature, context-independent.

Andrew confirmed the tension between the prominence of learning activities focussed on the development of technical knowledge and skills, and the broader goals for technological capability identified in technology curriculum and steering documents. He found that teachers were aware of this potential disparity between their personal construct of capability, and their decision about what to teach in the classroom.

As a result of his findings, Andrew developed an ecologically situated model of enacted practice which placed enacted practice as its focal point. The model distinguishes between situational and systemic amplifiers and filters of practice. Situational amplifiers and filters are everyday factors such as availability of resources or student demographics. On the other hand, systemic amplifiers and filters are viewed as factors which affect practices more broadly in the enactment of a subject, such as an examination system.

There developed three conceptions by teachers which formed their beliefs or intentions in teaching technology. They were: to obtain knowledge and skills for application, the ability to act in a technological way and the ability to think in a technological way. This may be useful to teach in challenging their assumptions about the nature of technology education.

1.2 Skills in Designing

The six chapters which constitute this second section of the book are based on research conducted in South Africa, the USA, Ireland and the Netherlands, attesting to some extent to the continued broad-based focus on the cognitive skills students need to be successful in Technology Education.

In her chapter, Anita Deck explores the timely topic of design-based learning for elementary teachers of Technology by implementing a series of professional development workshops with elementary teachers. The teachers initially did some teaching, then they underwent targeted professional development to revise their initial teaching approach to align with a design approach, and then retaught the unit.

The design-based learning approach adopted consisted of Problem identification, Ideation, Research, Potential solutions, Optimize, Solution evaluation, Alternations and Learned outcomes (PIRPOSAL).

The positive impacts of the professional development experience included a mitigation of the initial anxiety about the teaching of science concepts through their design-based approach to learning; the teachers were more easily able to design student activities which promoted higher order thinking; and although the teachers thought they understood relevant concepts prior to the professional development, after the PD, they realized that their understanding was incomplete.

Anita concluded that the professional development was effective in changing the participants' instructional use of the design-based learning phases of engagement to intentionally teach the specific concepts.

In Chap. 7 Dave van Breukelen also focussed on design-based learning as a pedagogy which enables the integration of science and technology. His thesis, however, is that the complexity of design interferes with conceptual learning, and that scaffolding and explicit teaching strategies can help to solve this problem. By analysing a design brief, it is possible to unravel what specific content is connected to the design problem (backward design), and this can help to deduce learning outcomes and to develop the learning task. Consequently, a design challenge can also address a coherent knowledge framework, through which students can be scaffolded.

The tasks Dave used in this research were (1) to design a battery-operated dance pad that let 13- to 14-year-old students use their feet to sound buzzers or flashlights. The dance pad had to consist of four self-designed, operating floor pads and one ready-to-use main power switch; (2) design a highly efficient solar power system for a model house by pre-service science teachers. These tasks were then modified and reintroduced by including explicit teaching and scaffolding strategies.

The modifications resulted in a significant increase in concept learning. This conceptual performance was accompanied by large increases in achievement levels among seven skill dimensions (negotiations, distribution of tasks/efforts, use and adequacy of prior knowledge, scientific reasoning, experimentation and self-checks). Furthermore, the study revealed strong positive correlations between concept learning and three skill dimensions: use and adequacy of prior knowledge and scientific reasoning. Dave suggests that by combining modifications and the traditional LBD approach a promising DBL strategy arises where students learn through providing a task focus, investigating scientifically what must be learned, informed application of content during Technological design activities and creating and explicating synergy regarding science and technology.

The focus of Neshane Harvey's Chap. 8 is the use of design as a pedagogy to teach values, which is particularly appropriate given the value-laden nature of technology. However, in the practice of technology education, technical values and values related to competence often take priority over moral values. As design education has been critiqued for a lack of opportunity for collaboration, Neshane suggests co-design as a solution whereby the designer and the user collaborate to co-construct social values.

The research focusses on three elements of Human Centred Design (HCD): users as a core and inspirational source, design with users and identifying user needs for integration with design. The research participants engaged in pedagogical strategies requiring them to role-play in design teams of two where one assumed the role of designer and the other that of user with autonomy to select design team members and respective roles. The intention was to create a culture of teaching and learning about the needs and values of users to combine with that of a designer.

Neshane found that design deliberations shifted to user views to validate that empathy does manifest when users are placed as a core and inspirational source to drive design because designers and users place themselves in the lived experience of the other person. Participants confirmed an empathetic approach because of created opportunities for designers to empathize throughout the process making them [user] be part of the entire process.

Educators concurred that design with users is advantageous in changing orthodox teaching practice because it's a novel new way of doing things which is going to become much bigger in the future. The shift in teaching practice created an opportunity to teach students to become future co-constructors, socially and politically responsive designers who understand that they can no longer design products and expect peoples' passive acceptance.

In Chap. 9, Eisuk Sung focusses his research on the topical approach of engineering design. The goal of his research was to enhance science learning by integrating engineering design into elementary classrooms by evaluating eight design challenges. In observing students' behaviours Eisuk found that when the elementary students responded to engineering design challenges they repeated patterns of design strategies. For example, students often start an engineering challenge with identifying problems and then move to the analysis process, where they research the constraints and criteria of the challenge. Also, when generating design solutions, they tended to move back and forth between questioning, predicting, and drawing stages of the engineering design process. The underlying idea of this study was the repeated design strategies form clusters of design patterns, and the collection of the clustered patterns characterize the design behaviours. The author believed that identifying patterns not only helps identify how students perform the engineering design but also provides a fundamental understanding of how students solve engineering problems.

The student participants spent almost half of the design challenge time Designing, and to a less extent Managing, Predicting and Analysing. Eisuk also conducted a sequential pattern analysis to identify the patterns of the sequential process of the engineering design strategies, finding that transitions from Analysing to Managing were more significant than other transitions. Recursive patterns were found in all of the design stages. There were bidirectional patterns between Defining Problems and Analysing, Analysing and Questioning, Analysing and Managing and Defining Problems and Managing. Cyclical patterns were also found between Questioning, Designing, Predicting, Modelling and Managing.

Other research showed that the use of informed sketching techniques with schematic symbols and strategic approaches led to quality design sketches and creative ideas. This study indicates that engineering design helps students expand their mental capacity through sketching, an externalized device for modelling mental images. This result implies a critical point that engineering and technology educators should not overlook the power of sketching in engineering design, including rough freehand sketching.

This research confirmed multiple pathways in the engineering design process. Engineering problems require creative and innovative solutions, and fixed, inflexible design processes yield uniform design solutions and do not offer creative solutions. In the research, the students did not follow a fixed design pathway, but tended to iterate several design strategies to explore solutions to the problem.

In the next chapter, Susheela Shanta identifies the difficulty that the assessment of engineering problem-solving skills in school is problematic because it is time-consuming to design the lessons for each aspect of the design process and evaluate problem-solving, as problems encountered may be unique to each team or individual. The assessment may also be time-consuming and cumbersome for a multitude of reasons: teamwork and collaboration require peer assessments and rubrics; creativity and communication are multifaceted and require separate assessments for each facet and there is no right or wrong solution thereby requiring subjective assessments based on many factors.

Susheela addresses these issues through the development of an assessment instrument with metacognitive questions and a related rubric for scoring student problem-solving skills when faced with an authentic design challenge. The primary finding from the administration of the rubric was that students immersed in an integrative STEM education programme where the pedagogical approach is design-based learning, performed significantly better in designing a solution to the challenge when compared with the performance of students in a traditional classroom. A secondary conclusion of this study was those four specific student skills (Sketch, Application of Physics, Application of Mathematics and Logical Progression) that are collectively known as problem-solving skills, which were strongly related.

In Chap. 11, Jeff Buckley builds on the existing evidence that spatial ability is positively associated with student education performance and retention in STEM generally, to position this skill within technology education. While there are many parallels between the STEM areas, technology education does have qualitatively unique characteristics such as the treatment of design and prevalence of provisional knowledge application.

Jeff's research revealed that students with higher levels of spatial ability performed better on a graphical task. This provided the first insight that spatial ability could be related to performance in at least certain aspects of technology education. It was also noted that students with varying levels of spatial ability engaged with the problem, students who had lower levels of spatial ability used some strategies more frequently (creating separate isometric sketches, indexing, labelling and editing) than those with higher levels of spatial ability.

Jeff also conducted a narrative literature review of spatial ability research which revealed many more spatial factors than are described in current frameworks, which was largely a result of technological advances leading to new possibilities for computerized testing of dynamic spatial factors. It also revealed that the visualization factor is the strongest indicator of a general spatial ability and describes the ability to mentally manipulate complex geometries.

As a result of this research a model was developed which indicated that intelligence in STEM was viewed as comprising three factors: a social competence which had the weakest loading on the student's overall conception of intelligence, a general competence and a technological competence which had the highest loading on their overall conception of intelligence.

1.3 Curriculum and Pedagogy

The tradition of research in Technology Education curriculum and pedagogy is strong and continues in this final section of the book, with the research situated in Mauritius, Lesotho, Sweden and South Africa.

In the first chapter in this section (Chap. 12) Chandan Boodhoo examines assessment for learning practices among technology teachers in Mauritius. This area of practice was selected because assessment for learning is characterized as a process where the teacher and students work in partnership, it focusses on providing qualitative insights into students' understanding, and is key to establishing effective teaching and student learning.

Chandan found that teachers did not routinely or consistently clarify and share learning intentions with students during their lessons, nor did they refer to their teaching plans during lessons. Although the teachers monitored students' work regularly, they did not use questioning strategies effectively to collect evidence of students' misconceptions. This was important because effective questioning is a key assessment for learning strategy, which teachers use to refine or redirect teaching to address misconceptions or extend a lesson through insights gained on students' progress.

The teachers mostly provided verbal feedback on students' ongoing work. They regularly identified the students' mistakes and told them what they needed to do next and how they needed to solve a problem or how to apply concepts. However, these verbal feedbacks were short and often ended abruptly. The feedback during questioning did not allow a full exploration of the ideas or issues discussed.

Chandan concluded that the teachers were not reflecting effectively when monitoring assessment activities, and therefore their assessment for learning practices was ineffective.

In Lesotho, the Technology Education curriculum emphasizes the development of entrepreneurship, and this was the focus of Nthoesele Mohlomi's chapter. Design and Technology is integrated with Entrepreneurship and starts from Grade 1. The role of teachers is to integrate D&T with Entrepreneurship to inculcate skills, knowledge, attitudes and values at an early stage of life. These are expected to allow learners to realize their creative capacity with the resources in their environment, and as a result be able to be socially and economically productive in their everyday living.

Nthoesele found that there are two groups of teachers: some who can exploit suitable resources around their schools and use them profitably regardless of their school location and link school with the world of work, while others are only using the prescribed materials without linking them either to the environment around or to industry.

The teachers identified challenges associated with achieving the entrepreneurship outcomes: the teacher–pupil ratio (1:40 or more) prevents them from giving each learner special attention since the curriculum prescribes that they should identify the talents and abilities of each learner and address them differently as learners are different. Secondly, they indicated the mismatch between the way they were trained (discipline orientated) and what they are expected to do (transdisciplinary).

Nthoesele cites one school in which learners produced stirring rods made of aloe agave, and bracelets and earrings made from paper and wire. On Friday afternoons, Grade seven learners would go to the main road to sell their artefacts produced in the class. They had fixed prices for their artefacts throughout the month but at the end of the month, the prices increased. The money collected from sales was saved to help orphans in the school.

Overall the findings show that the concept of entrepreneurship integrated with Design and Technology has relevance to local economies and takes cognizance of emerging socio-economic activities in Lesotho. However, there is a challenge to educators' planned actions towards learning as teacher's backgrounds and norms are still inclined towards a colonial inherited educational system.

In Chap. 14, Pernilla Sundqvist examines the nature of preschool technology education. In 2010 a revision of the curriculum in Sweden included technology as a content area for preschool education and teachers have had to adjust to this vaguely defined area of technology.

Pernilla discovered that a broad range of technological content was described by the preschool staff, with a focus on technological objects and building activities. The categories included simple everyday activities such as using cutlery when eating lunch, as well as more complex content, such as exploring the adequacy of technological objects and materials, how technological objects, and systems work, and what makes a stable construction.

Each of the teachers had different ways of characterizing technology education: using technological objects, doing experiments, developing abilities, objects and systems in the child's environment, naturally through play and through digital technologies. The study has found two main challenges that negatively affect the teaching of technology. The first challenge is that it is not clear to all preschool staff what technology is and what should be taught in preschool when it comes to technology.

Some mix up technology with other content areas, like science, and view the use and learning of techniques as technology.

The second challenge is how to teach some specific technological content in a play-based preschool. For a teaching activity to be regarded as technology education, technology needs to be the goal. For instance, building activities can be used as means to learn math or to collaborate, or a computer tablet can be used to learn about animals. However, in these cases the goal is not technology, so it is not technology education.

The research showed that two important technological content areas are problematic for preschool staff to teach. The content addressing how technological objects and systems work was observed to be taught only when children requested it—when they showed specific interest or explicitly asked questions about how something works. The other content that seems problematic to teach is what technology is, which was not observed to be taught at all. Pernilla concluded that the main challenge with teaching technology in preschool is the staff uncertainty of what technology is and what technology education in preschool is.

Richard Maluleke's chapter discusses the need for a culturally relevant pedagogy to be adopted in technology education in order to promote indigenous technologies. The South African curriculum includes indigenous technology, and such a focus is seen as a counter to the perpetuation of a western-oriented colonial curriculum which hinders meaningful learning in contexts such as South Africa which have many indigenous learners in their schools.

Richard discovered that Technology students sometimes do not understand Technology lessons that do not integrate indigenous technology. The teachers considered that the use of pedagogies which exclude the cultural experiences of learners might contribute towards their inferior performance, and that that culturally relevant pedagogy can be used to teach learners from the perspective of their socio-cultural contexts to so promote the smooth acquisition of design skills.

He also found that indigenous learners are curious about indigenous technology and the skills used to make indigenous artefacts—their knowledge and skills can therefore be retained more effectively if their learning is inspired by curiosity. Consequently, discovery teaching can promote the integration of indigenous technology in teaching design skills.

The participants in this study further indicated that the knowledge of indigenous design might stimulate creative and critical thinking in learners. Indigenous experts do not really follow 'prescribed' steps in a design process, which implies that students should not be coerced into following specific design steps, but should be given the latitude to find fresh solutions creatively. Relevant design principles can still be ensured even in flexible design processes. The participants also indicated that indigenous people learn to design through experience and only contemplate the steps they have followed designing a product in retrospect. In this sense, the findings showed that indigenous people concentrate on experimentation rather than on the process. Technology learners should therefore be introduced to designing through experimentation.

The final chapter in this section by Anna Otterborn focusses on the use of digital tools in preschool education. Anna indicates that, although preschools have worked with these tools for a number of years, little is known about what actual activities teachers implement and perform in practice and how digital tablets can be effectively integrated.

The research revealed eight categories of implemented pedagogical activities by teachers. The categories included documentation and reflection, developing the use of language, hands-on and active exploration of technology and science content (including programming activities), engaging and developing mathematics concepts and skills, critical thinking, cooperation and values and thematic approaches involving focussing on a particular content area or project.

Many preschool teachers expressed a lack of knowledge (i.e., what can be done with digital tablets to support my pedagogical work?) and feel insecure (i.e., how do I perform it?) with respect to digitalization. On the other hand, the teachers also indicated that they placed a strong emphasis on integrating programming activities in combination with digital tablets. Two-thirds of the respondents stated that they programme together with the children. Almost half of the educators noted that the programming work stemmed from their own initiative. Various apps (such as Blue-Bot, Bee-Bot and Lightbot Jr.) and accessories (such as robots) are used together with digital tablets in connection with programming activities.

The editors would be delighted to hear from any researchers who have recently completed doctoral-level research in technology education as we plan to continue this series of 'Helping teachers develop research informed practice' volumes and of course from any teachers who use the contents of this book to develop their practice. This is the third book in this series.

P. John Williams is a Professor of Education and the Director of Graduate Research in the School of Education at Curtin University in Perth, Western Australia, where he teaches and supervises research students in STEM and technology education. Apart from Australia, he has worked and studied in a number of African and Indian Ocean countries and in New Zealand and the United States. His current research interests include STEM, mentoring beginning teachers, PCK and electronic assessment of performance. He regularly presents at international and national conferences, consults on Technology Education in a number of countries, and is a longstanding member of eight professional associations. He is the series editor of the Springer *Contemporary Issues in Technology Education* and is on the editorial board of six professional journals. He has authored or contributed to over 250 publications, and is elected to the International Technology and Engineering Education Association's Academy of Fellows for prominence in the profession.

Belinda von Mengersen is a specialist in traditional, current and emerging textile technologies, and leads Design and Technologies at the National School of Arts, Australian Catholic University. She has authored chapters in three volumes of Springer's Contemporary Issues in Technology series, regularly reviews articles for the International Journal of Technology and Design Education and presents frequently at International Design and Technologies conferences including PATT, TERC and DAATArc. Belinda focuses on reflective, creative and speculative writing in design practice, practice-led research in design, the intersection between signature pedagogies of visual arts, design and technology, and the dynamic and interdisciplinary nature of design-related fields.

Part II
Perceptions and Practices

Chapter 2
Leadership Perceptions in Design and Technology Education

Paul Kinyanjui Mburu

Abstract This qualitative research examines leadership in Design and Technology departments in secondary schools in England. This research focusses on the perceptions of Design and Technology subject leaders about their practices in sustaining and developing the subject in the secondary school curriculum. The work of Design and Technology subject leaders is demanding notwithstanding the subject's historical struggle with low status (Paechter, 1993). In the England's national curriculum, Design and Technology is a distinct subject, which is compulsory for pupils aged 11–14 years in state schools. Beyond this age group the subject is optional. However, the way the subject is defined in the national curriculum remains different from its form in schools. For example, in England, an amalgamation of separate subject areas including and not limited to product design, resistant materials, graphics, systems and control, electronics, timbers, papers and boards, and textiles are studied under the banner of Design and Technology. Through the analytical lens of cultural historical activity theory (CHAT) this research broadens the understanding of subject leaders' perceptions about their practice of monitoring teaching and learning, building relationships, and highlighting Design and Technology. The findings illuminate that sustaining and developing Design and Technology in the school curriculum relies on the subject leader's department context settings.

Keywords Design and technology · Subject departments · Leadership · Subject leaders · Cultural historical activity theory · Activity systems

2.1 The Questions I Asked and Why They Are Important

Subject leaders of the Design and Technology departments in secondary schools face exceptional challenges in their job, especially given the contrasting understanding that stakeholders have about the subject. For example, parents see it as a non-academic subject that does not belong alongside subjects such as science,

P. K. Mburu (✉)
Roehampton University, London, UK
e-mail: mburup@roehampton.ac.uk

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_2

history, and languages (Hardy, 2015b). However, the importance of subject leaders' work as middle leaders in secondary schools is significant as they try to improve the profile of Design and Technology. Research in school subject departments has shown that subject leaders play a vital role in setting direction and the success of both the department that they lead and their school. This could be attributed to their practices and ability to bring different perspectives to school decisions by virtue of their subject or discipline specialisations (Leithwood, 2016). However, little has been written in the literature about how Design and Technology subject department leaders in secondary school perceive their practice. Since the available literature does not answer all the questions and fill the gaps on Design and Technology subject department leadership this research aims to address this gap.

School subject departments are fundamental boundaries forming distinct subcultures within the school (Siskin, 1991). They provide the most common organisational vehicle for school subject knowledge in secondary schools (Goodson & Marsh, 1996). Design and Technology, which was introduced in the national curriculum for England in 1990 forms an example of a subject department. Design and Technology as a subject has undergone several changes, for example, narrowing the curriculum (Constantinou, 2019) and being relegated to an option subject at GCSE and Post-16. Over the years Design and Technology has struggled with status between its constituent subject specialisms in comparison with other curriculum subjects. To date Design and Technology has continued to grapple with its status in schools and the latest introduction of English Baccalaureate in England has left the subject with a reduced number of students at key stage 4 (15–16-year-old pupils studying GCSE examination subjects) and at Post-16 (16–18-year-old pupils studying GCE examination subjects).

Those directly dealing with these changes and challenges are the formally appointed teachers in-charge of leading Design and Technology departments whose focus is on teaching and learning that pervades through the constituent specialist subjects. In this research, these teachers are referred to as subject leaders of Design and Technology. The research is based on the belief that subject leaders of Design and Technology departments have influence on their subject community, which includes teachers, parents, pupils, school leaders, and other stakeholders. At an operational level, subject leaders work to achieve the objectives or goals of their school, through their day-to-day duties and interactions (Thorpe & Melnikova, 2014) at the department level.

The main research question that guided this research was: *What are the perceptions of subject leaders of Design and Technology subject leaders about their practices of sustaining and developing the subject (Design and Technology) in the secondary school curriculum?* This main research question is further broken down into two research sub-questions.

1. How are leadership tools directly used and appropriated by subject leaders in Design and Technology department leadership activity systems?
2. How do subject leaders of Design and Technology raise the profile of the subject in their school?

2.2 How I Tried to Answer the Questions

To understand the practices of subject leaders in subject department contexts in schools, a qualitative multiple-case study positioned in an interpretive paradigm was designed. As an exploratory study, each case in the multiple-case study design was an individual unit that embraced more detail, richness, completeness, and variance (Flyvbjerg, 2011). This offered a ground to generate data to compare how leadership practice differed across school department contexts. Consequently, the study involved several cases, each with its own uniqueness and complexity was studied to form a collective understanding of the practice of subject leaders.

The research questions were addressed through field visits to six Design and Technology departments in six secondary schools. The field visits generated nine interviews with participants, numerous in situ field notes (on observations of subject departments office/tearoom, a department meeting, displays, and artefacts on classroom walls and corridors around Design and Technology departments and the school) and analysis of documents that were provided by participants as well as those that were available in the public domain. The dataset comprised of field notes written in situ, transcripts of transcribed interviews, and documents. This meant that the fieldwork was initially dictated by the field rather than by the pre-planned theoretical framework (Douglas, 2011). Gaining familiarity with the field through a guided tour by the participating subject leader steered early data generation, where features that seemed relevant to the leadership of a subject department were recorded. Subsequent visits to the field allowed compilation of notes based on observations, which were detailed summaries of events and initial reflections (Bryman, 2016). Semi-structured one-on-one interviews were used to collect personal views from participants. The decision to use semi-structured interviews was based on the need to gain information on subject leaders' opinions, insights, interpretations, and experiences. All the interviews were digitally audio-recorded and thereafter transcribed verbatim.

Further data was collected from documents as supplementary information to help understand subject leader's interpretations of their role. This meant that documents were used to corroborate and augment evidence from other sources (Yin, 2009), that is, field notes and interviews. Data items in this study were first subjected to a thematic analysis as a way of reporting themes within qualitative data and as an initial step in data analysis (Braun & Clarke, 2006). The thematic analysis step began by engaging in an iterative process of reading and rereading the transcribed transcripts until common themes emerged. Data was further viewed from the analytical tools of cultural historical activity theory (CHAT) (Engeström, 2001). CHAT concepts guided the discussion of data on the leadership practice of subject leaders on the complex settings of school departments.

2.3 What I Found Out

This section discusses the findings that emerged during thematic analysis of data (Braun & Clarke, 2006). The three themes that are presented below are monitoring teaching and learning, building relationships, and showcasing Design and Technology.

2.3.1 A Brief Description of the Participants

All the participants were subject leaders and specialist teachers of Design and Technology who taught in state-funded secondary schools for 11- to 18-year-olds. The pseudonym names for the six participants are Adam, Nikki, Jim, Jack, Jaspal, and Theo.

1. Monitoring teaching and learning

The participating subject leaders were involved in tasks that enabled them to monitor the work of their department colleagues. Data revealed that these tasks were driven by their schools' senior leadership team. However, each subject leader interpreted the tasks differently. The tasks included learning walks, which were short visits to colleagues' classrooms; lesson observations that involved a once a term visit for about thirty minutes to colleagues' classrooms; and book reviews that involved looking at a set of class books from each colleague to identify the written feedback that had been provided to pupils.

2.3.2 Learning Walks

Adam used learning walks to identify weaknesses and then developed a strategy to address them:

> we do learning walks … I pop into lessons now and then and have a look around and I look through books then … just to see what is going on and to see what feedback that has been given … that gives me a clear idea so then I know what I can target … I am looking to pick up weaknesses and work out strategies to improve those … like sharing good practice and things like that. (Adam, interview)

Adam also involved other staff members in his large department to complete learning walks:

> I have Mr* as the head of food, he has responsibility, Ms* is head of textiles, Ms* is head of resistant materials … so I get those three working for me … because they know what is going on in their subject areas. (Adam, interview)

Unlike the other subject leaders of Design and Technology, Adam's approach was unique as he delegated to other teachers in the department who had responsibility for specialist subjects. Adam used the outcomes of learning walks for developmental purposes that aimed to raise the quality of teaching in the department. The inclusion of other teachers in the monitoring process showed Adam's focus on collegiality and support for leadership growth in the department. This illustrated how Adam perceived inclusivity in monitoring the quality of teaching and learning.

The directness in learning walks was not perceived in the same way across the case studies. For example, Nikki's approach to learning walks was duplicitous as she revealed that:

> I do learning walks … if I have time I walk into classrooms … I make them feel very comfortable so I just walk in I pretend I am making tea but really I am watching and you know … I am always popping in … I know how they teach, you know. (Nikki, interview)

This indicated how Nikki was concerned about establishing a good professional working relationship with her colleagues and at the same time monitoring their work. Consequently, Nikki's approach corresponds with Wise's (2001) view that middle leaders avoid damaging their good relationship with their team members by instituting formal monitoring procedures. Nikki appeared to use an established department culture of 'we always have our doors open' (Nikki, interview) to access colleagues' classrooms. Similarly, Theo like Nikki relied upon an open-door policy while completing learning walks in his department:

> I also do learning walks … people don't have a problem with other people coming into their rooms. (Theo, interview)

Having an open-door policy was seen to be important when subject leaders were completing learning walks in their departments. However, it also showed the subject leaders' position in their respective schools' hierarchy, which enabled them to exert their influence on subject teachers.

2.3.3 Lesson Observations

Like learning walks, the participants' interview data and documents showed that lesson observations afforded spotting and confirming good practice in the department, as well as identifying areas of further development. Lesson observations were completed by subject leaders at least once in a term and the outcome was shared with the other members of staff in the department.

2.3.4 Student Book Reviews

Findings revealed that student book reviews were conducted and viewed differently by the participating subject leaders. For, example, Adam stated that:

> we do as a means of sharing good practice … we have a look at what each other is doing … we share books. (Adam, interview)

The above comment shows how Adam facilitated and organised the interaction of the department staff by overseeing the book check activity and ensuring it was being 'done well' (Adam, interview). Adam chose to use book reviews as a means of sharing good practice in the department 'other than working the other way' (Adam, interview) that is fault-finding in the work of teachers. Adam's actions are consistent with De Nobile's (2014) view that subject leaders' staff development role involves building the capacity and competence of staff members so that they can do their job more effectively. Comparing Adam's approach to Nikki's, differences can be seen in their perceptions about book reviews. Nikki explained that:

> we get book looks … they monitor the books … the book look I do feel they are very constant … you know once a week … because every week you know that the children will be chosen … it is just something that I wish I could just forget …. and if it happened once a term, I know that would be great … not to worry about. (Nikki, interview)

In the above excerpt Nikki considered book reviews as an unreasonably demanding task from her school's senior leaders' agenda. It may be argued that Nikki's view corresponds to Leithwood's (2016) conclusion that head teachers view department heads merely as conduits for their own initiatives and leave little room for department-head initiative. Nikki rejected the demand to keep pupils' books ready for senior leaders' monitoring. However, she was happy to complete the exercise as a departmental monitoring task rather than as a managerial task. This way of working indicated that Nikki preferred developing departmental practice rather than whole school issues. In addition, evidence from documents that were gathered from Jaspal and Jack revealed that they had the responsibility of completing student book reviews to raise the quality of teaching and learning in their departments. Both Jack and Jaspal had to complete a book review rubric that identified the strengths and areas of further development for each member of the department staff. This rubric was later shared with department colleagues and the school's senior leaders.

2. Building relationships

Findings indicated that there were similarities and differences between how subject leaders of Design and Technology in different schools build relationships with their department staff. Data revealed that participating subject leaders had preferences in steering their department towards a desired vision. For example, Nikki stated that 'it is time you know you just need to constantly be on top of people' (Nikki, interview), which was a form of control. However, Jack and Adam revealed that team building was a challenge, especially after members of the staff in the department left and new ones joined. Having new department team members who 'had new attitudes and ways of working' (Adam, interview) strained building relationships. The openness to other people's views was evident in subject leaders, for example Jaspal explained that:

> I ask for input because it is important to me and sometimes, I will go with things that other people want but I don't want … but it is all about give and take because there some things I would not have a conversation about. (Jaspal, interview)

Informal conversations or 'loads of talk' (Nikki, interview) along the corridors and in department office/tearoom were used to support relationships in subject departments. However, data revealed that formal department meetings had their place in keeping department staff intact. Although the overall aim was to have a department team that cohesively worked together, it is evident that the participating subject leaders' approach to building relationships differed. Subject leaders engaged in practices that suited their department context in building relationships.

3. Showcasing Design and Technology

The status of Design and Technology as a curriculum subject in secondary schools is an issue in England. The uptake of the subject as an optional examination subject after key stage 3 (pupils aged 11–14) has been in a steady decline since 2000 (Hardy, 2015b). Findings in this research indicate that subject leaders were actively promoting Design and Technology to pupils and their parents. This was aimed at raising the number of pupils choosing Design and Technology as an examination subject beyond key stage 3. Some participating subject leaders revealed how Design and Technology as an optional examination subject at key stage 4 had to compete for pupils for it to be retained in their school curriculum. For example, Adam explained how English Baccalaureate (EBacc) had impacted Design and Technology:

> We have suffered from the EBacc literally when that started being promoted … thirty to forty kids move from Design and Technology to humanities literally within a year … and now our groups are quite small … our GCSE (Graduate Certificate in Secondary Education) numbers probably about twelve … fourteen. (Adam, interview)

Similarly, Theo stated that:

> we are in so much competition with all the other subject areas … the numbers for GCSE and A level are very low … because that is sadly how technology has become … Maths, English and Science sit very comfortably now and the rest of us squirrel for the remaining places. (Theo, interview)

The above interview excerpts illustrate how Design and Technology was 'losing potentially kids in the future that could be the next big designer' (Jim, interview). The participating subject leaders put in place and used their schools' existing communication structures to support the promotion of Design and Technology. Although data revealed a range of methods that were used to promote Design and Technology, these were not applied evenly across the case studies. One-off techniques that were used to communicate to parents and pupils regarding Design and Technology included parents' workshops, options evening, options assembly, taster lessons to prospective key stage 4 pupils, talks by pupils studying Design and Technology at key stage 4, and an exhibition promoting pupils' work in the Design and Technology department to the school community. Intermittent methods included newsletters/magazines, internal and external Design and Technology competitions, postcards, letters to parents, trips, displays on school TV screens, and updating the school website pages that contained Design and Technology content. Continuous methods of communication included displays on the Design and Technology corridor and classroom walls and pupils work on display cabinets in the department and around the school. Data revealed that the method used to promote Design and Technology was dependent on the department context and the wider school settings.

In addition, regarding a reduction in the Design and Technology curriculum time in his school, Jim disclosed that:

> next year if we do go to a more reduced time … if we end up losing a quarter of the time effectively over the key stage then … it is going to be difficult what we slash. (Jim, interview)

The subject leader appears to be concerned about the impact that a reduced curriculum time would have on Design and Technology. He saw this as an attempt to further diminish Design and Technology curriculum time that was already 'overstretched'. This was seen by Jim as a deliberate choice that pushed back the provision of a valuable curriculum subject to pupils.

2.4 A Cultural Historical Activity Theory (CHAT) Analysis

CHAT was a term coined by Cole in 1996 (Edwards, 2011), and it is philosophically rooted in Marx's concept of reality (Foot, 2001). In CHAT an activity is undertaken by a subject using tools to achieve an object, thus transforming it into an outcome (Kuutti, 1996). This means that an activity emerges through a process that transforms the subject, the object, and the relationship between the two and their context (Davydov, 1999 cited in Yamagata-Lynch, 2003). Through CHAT the interactions of subject leaders can be analysed by considering their use of tools in the social settings of subject departments. An important strength of CHAT in understanding subject leaders' perceptions of their practices is its notion that tool mediation is fundamental to all human activities. This significance of tools, for example, lesson visits alongside other tools, as mediators of activity focusses attention on the activity itself rather than simply the interaction between the subject leader and the tool (lesson visit in this example). Therefore, the subject leader is doing something rather than using the tool. This in turn affords an understanding of how the tool supports subject leaders in their leadership activities giving an indication of how they see the object that they are working towards.

Specific practices in a school subject department are embedded in the tool-mediated, and object-oriented leadership activity system (Engeström, 2001). Applying CHAT concepts in the analysis of subject leaders' practices by considering the context of their leadership as an activity system helps to focus on the social context of their interactions. Sustaining and developing Design and Technology is one of the many activities in the Design and Technology department leadership activity system. The activity can be explored by considering how subject leaders interpret the *object* of the activity. The *object* of the activity is the physical or mental product that is sought with the object being acted on by the *subject* (Jonassen & Ronrer-Murphy, 1999). *Subjects*, for example, subject leaders of Design and Technology in this research, do not act on the *object* (for example, working to build collective team learning) directly, their actions are mediated by tools, and it is the tools that transform the object (Lofthouse & Leat, 2013). Thus, by means of *tools* (for example, learning walks, lesson observations, book reviews, subject leaders' knowledge, subject department meetings, informal conversations, and promotional materials, for example, department newsletters), *subjects* (subject leaders in this research) in the activity of sustaining and developing Design and Technology in the school curriculum work on the object of the activity.

Although tools appeared to be the same, subject leaders appropriated them differently. While appropriating department meetings as a tool, subject leaders viewed them as a way of establishing productive working relationships with the department staff. For example, Jack appropriated the department meetings tool to demonstrate the significance of good practice by recognising the work of individual department staff members. Department meetings were an 'opportunity to talk about … to share … with the other members of the department something I have seen in their lesson observations and that works quite well' (Jack, interview). The subject leader's perceptions reveal that the use of tools was dependent on their department contexts.

The appropriation of the tool that was book reviews differed between subject leaders. To one subject leader, book reviews were unnecessary, 'a lot' (Nikki, interview) and hardly contributed to the work of the department. However, to another subject leader, book reviews were used for developmental purposes to harness the different classroom practices as exhibited by the department staff. Book reviews were viewed as an opportunity for collective learning by department colleagues, 'so we bring a set of books in, and we have a look at what each other is doing … we share books' (Adam, interview). Using CHAT revealed how subject leaders viewed and performed their leadership role differently with tools that were available to them within their Design and Technology department leadership activity system.

2.5 How This Might Be Used to Improve Teaching and Learning

This section elaborates on how this research might be used to improve teaching and learning and focusses on monitoring teaching and learning, building relationships with a department team, and communicating the subject's vision.

2.5.1 Monitoring Teaching and Learning

Subject leaders' observation of classroom practice of their colleagues involved completing learning walks, lesson observations, and book reviews. Although some participating subject leaders saw themselves as custodians of the quality of teaching and learning in their departments, such practices were not their preserve; they involved other members of the department and their school's senior leadership team.

The outcome of observing classroom practice was used differently by participating subject leaders. This included a developmental approach as opposed to a tick box exercise by the subject leader. In addition, opportunities for subject leaders to use their subject expertise to improve teaching and learning were evident in this research. Therefore, the role of monitoring teaching and learning in departments was perceived by participants as theirs. This creates the opportunity for subject leaders to revise their approach to monitoring teaching and learning and view it as a collective activity. This means that learning walks, lesson observations, and book reviews in Design and Technology departments be seen by subject leaders as means of improving collective practice.

This research revealed that a collective approach and debates on teaching and learning were enhanced by subject leader's working practices, such as department meetings and sustained informal conversations. For example, Jaspal used department meetings to discuss expected classroom practices with his team. Specifically, Jaspal discussed with the department staff a checklist of requirements to be met during lesson walkthroughs and observations. Likewise, Theo utilised department meetings to review pertinent local issues about teaching and learning, such as, 'pupil discipline, target setting, reports, student interventions, letters and calls home' (Theo, interview). It is worth noting that these tasks were approached jointly to enhance pupils' learning in Theo's department. Similarly, for Jim, department meetings were centred on teaching and learning, 'whether that is doing a bit of moderation … looking at changes to GCSE … curriculum planning based' (Jim, interview). These views imply the importance of building department practices around open conversations on teaching and learning. This emphasises subject leaders' approach to department meetings as a tool for discussing the department's teaching and learning issues. This way of working by subject leaders encourages collective and individual professional development that could be adapted to suit local contexts. Therefore, subject leaders could provide teachers in their department with an opportunity to reflect on their practice.

Findings in this research, showed that subject leaders' practices, for example, the monitoring of classroom practice and building relationships with department teams were pursued alongside communicating their vision of the subject to stakeholder groups (Hardy, 2015a). It is essential that the stakeholder knowledge of the subject is driven by an understanding of its clarity of purpose and sound epistemology (Barlex & Steeg, 2016). Therefore, vision in this discussion is seen in terms of the subject leader's ability to use available resources as a means of sustaining and developing Design and Technology in their school curriculum. Opportunities for communicating the vision for participating subject leaders may have appeared to be similar, as they worked in a Design and Technology subject department context. However, when considering how the opportunities for communicating the subject's vision were constructed, there were disparities between the participants. Therefore, the potential for subject leaders to have a clarity of purpose when engaging with different stakeholders differed. For example, Jaspal considered it necessary to have a clear message to both parents and pupils:

> all the parents and students come … there is a talk in the hall … there are displays up … where everybody can go and have a look at all the displays that show the work that students do. (Jaspal, interview)

This approach meant that Jaspal gave parents and pupils an opportunity to experience together some aspects of Design and Technology. Equally, contestation was also acknowledged, as it was recognised that different members of staff in Jaspal's school had different opinions about Design and Technology. Consequently, he exhibited work of pupils, 'that might struggle in other subjects … for staff are impressed … and that has helped to change staff perception' (Jaspal, interview). From a subject leader perspective, it may be important to create a sustained drive to inform all the stakeholders about the department. This could result in a common approach that involves both the teachers in Design and Technology departments and their subject leader in promoting the subject to stakeholders.

This study's findings showed that Nikki's and Adam's way of working led pupils 'to discuss their learning with their parents, carers, and other family members' (Barlex & Steeg, 2016). This suggests that pupils and their parents engaged in talking about the views that subject leaders had presented about Design and Technology. Consequently, the differing approaches to communicating about the subject of Design and Technology to stakeholders present subject leaders with opportunities to consider the effectiveness of teaching and learning in Design and Technology. This indicates the ability of subject leaders to connect classroom practices to team building and communicating the subject's vision, which may strengthen teaching and learning in their departments.

2.6 Conclusion

In this research, I have presented an analysis of subject leaders' perceptions about their practices in sustaining and developing Design and Technology in the secondary school curriculum. The qualitative data that was collected for this research illustrates the complexities that subject leaders of Design and Technology departments contend with. These include showcasing the subject to stakeholders, monitoring of classroom practice of their colleagues, and the intricate task of building and maintaining professional relationships. In discussing building relationships, I have argued that some subject leaders find this unproblematic, while others have the delicate task of maintaining professionalism and keeping their department staff focussed on a shared approach. In this regard, practicing subject leaders could engage in action research by creating opportunities for teachers in their departments to lead aspects of teaching and learning. This way of working could allow teachers to view classroom practice as shared practice rather than a way of scrutinising their work.

The subject leaders in this study held complex understandings on why and how Design and Technology mattered, and they saw it as important to communicate their perceptions to pupils and their parents. This research revealed that there are significant opportunities for subject leaders to develop ways of understanding how pupils, their parents, and other stakeholders understand what Design and Technology (the subject) is. This in turn will help subject leaders to improve their approach in communicating about the subject. Maximising the use of parent and student voice to find out what they think about Design and Technology could assist subject leaders to develop the subject in their unique department contexts. Similarly, the views that subject teachers in the department and the school's senior leaders hold about the Design and Technology department in their school could be qualitatively captured. This would be beneficial to subject leaders in developing their own practice and that of their department team. The aim of these suggestions is to help subject leaders to understand in detail the unique context of the department that they lead.

References

Barlex, D., & Steeg, T. (2016). *Re-building design & technology*. Retrieved May 30, 2020, from https://dandtfordandt.files.wordpress.com/2016/12/re-building-dt-final1.pdf

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Bryman, A. (2016). *Social research methods* (5th ed.). Oxford University Press.

Constantinou, F. (2019). Strong and weak 'brands' in the school curriculum: Towards a framework for levelling the curriculum hierarchy. *Research Papers in Education, 34*(5), 553–568. https://doi.org/10.1080/02671522.2018.1481139

De Nobile, J. (2014). Examining middle level leadership in schools using a multi-role framework. Paper presented at 'Passion & Purpose: Setting the Learning Agenda', Australian Council for Educational Leaders National Conference, Melbourne, 1–3 October 2014. Retrieved August 1, 2019, from https://www.researchgate.net/publication/271508043

Douglas, A. S. (2011). Learning on the job: A cultural historical activity theory approach to initial teacher education across four secondary school subject departments. *Ethnography and Education, 6*(2), 195–211.

Edwards, A. (2011). Cultural historical activity theory, *British Educational Research Association on-line resource*. Retrieved April 4, 2020, from https://www.bera.ac.uk/researchers-resources/publications/cultural-historical-activity-theory-chat

Engeström, Y. (2001). Activity theory as a framework for analysing and redesigning work. *Ergonomics, 43*(7), 960–974.

Flyvbjerg, B. (2011). Case study. In N. K. Denzin & Y. S. Lincoln (Eds.), *The Sage handbook of qualitative research* (4th ed.). SAGE.

Foot, K. A. (2001). Cultural-historical activity theory as practice theory: illuminating the development of a conflict-monitoring network. *Communication Theory*, *11*(1), 56–83.

Goodson, I., & Marsh, C. (1996). *Studying School Subjects: A Guide.* The Falmer Press.

Hardy, A. (2015a). What's D&T for? Gathering and comparing the values of design and technology academics and trainee teachers. *Design and Technology Education: An International Journal, 20*(2), 10–21.

Hardy, A. (2015b). *Why has the number of teenagers taking design and technology GCSE dropped?* Retrieved August 3, 2020, from www.data.org.uk

Jonassen, D., & Ronrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research and Development, 47*(1), 61–79.

Kuutti, K. (1996). *Activity theory as a potential framework for human-computer interaction research*. Retrieved August 23, 2020, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.92.5417&rep=rep1&type=pdf

Leithwood, K. (2016). Department-head leadership for school improvement. *Leadership and Policy in Schools, 15*(2), 117–140. https://doi.org/10.1080/15700763.2015.1044538

Lofthouse, R., & Leat, D. (2013). An activity theory perspective on peer coaching. *International Journal of Mentoring and Coaching in Education, 2*(1), 8–20.

Paechter, C. (1993). What happens when a school subject undergoes a sudden change of status? *Curriculum Studies, 1*(3), 349–363.

Siskin, L. S. (1991). Departments as different worlds: subject subcultures in secondary schools. *Education Administration Quarterly*, *27*(2), 134–160.

Thorpe, A., & Melnikova, J. (2014). The system of middle leadership in secondary schools in England and its implications for the lithuanian education system. *Education in a Changing Society, 1*, 33–39.

Wise, C. (2001). The monitoring role of the academic middle manager in secondary school. *Educational Management and Administration, 29*(3), 333–341.

Yamagata-Lynch. (2003). Using activity theory as an analytic lens for examining technology professional development in schools. *Mind, Culture, and Activity, 10*(2), 100–119.

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). SAGE.

Paul Kinyanjui Mburu is a secondary school Design and Technology teacher with over 18 years of classroom practice. Currently, he is the Head of Design and Technology department in a large comprehensive secondary school in West London. His research interest is in school leaders particularly in the leaders of subject departments.

Chapter 3
The Formation of Science, Technology, Engineering, and Mathematics Teacher Identities: Pre-service Teacher's Perceptions

Dawne Irving-Bell

Abstract Set within the context of Science, Technology, Engineering, and Mathematics (STEM), this chapter presents an overview of findings from my doctoral study that explored the personal teaching philosophies of students (pre-service teachers) training to become qualified teachers, with the intention of better understanding how my participant's perceptions of teaching were shaped by their previous experiences of learning. Having established the focus, I set about designing my study. Evaluating my own philosophy, values, attitudes, and beliefs I chose symbolic interactionism as my theoretical approach and adopted a research strategy informed by grounded theory. Many themes of potential interest emerged including subject knowledge, disciplinary differences, and engendered approaches to STEM pedagogy. The key finding and hence topic under discussion within this chapter examines how the meanings pre-service teachers assign to their lived experiences are significant in their development as teachers. Outcomes are discussed within the context of policy and practice, and the chapter closes by offering potential strategies, ways forward that I hope may be supportive in helping pre-service teachers and teachers of STEM-related subject disciplines to become more aware of the meaning they have assigned to their experience-related beliefs, how awareness can support the development of professional teacher identities and how this in turn may be used to improve learning and teaching.

Keywords STEM · Learning and teaching · Pedagogy · Pre-service teachers

3.1 Why Did I Want to Undertake This Study?

As an advocate for 'STEM education,' having taught in schools for many years before moving into Initial Teacher Education (ITE) I was, and still am, acutely aware of the challenges faced, not only in recruiting but retaining teachers. Teaching is an

D. Irving-Bell (✉)
Edge Hill University, Ormskirk, UK
e-mail: Belld@edgehill.ac.uk

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_3

extremely rewarding profession, but it can be tough. I have always been fascinated by the motivations of those seeking to become teachers. Particularly those seeking to qualify as teachers of the STEM-related subject disciplines, which let us face it are not always the most popular with children. So, what I wanted to know is how these motivations translate into teaching behaviours. What, in practice, does that mean for the teacher? Their approaches to their own learning, how that translates into approaches to teaching and subsequently what does that look like to the students as learners?

According to Lortie (1975) our values and beliefs about teaching, how a teacher should act and behave form at an early age (Hargreaves, 2010). So, applying this notion to my investigation I wanted to know how pre-service teachers' experiences as learners (their experience-related beliefs) influence not only approaches to their own learning but how these beliefs influence and impact upon their development as teachers.

3.2 Preparing to Research

In preparation for my study, I explored literature from the field: the influence experiences have on identity construction (Bukor, 2015), teacher commitment (Day et al., 2006), and studies which addressed teacher development within the context of learning and teaching (Lindblom-Ylänne et al., 2006; Prosser & Trigwell, 1999; Trigwell et al., 1999; Van Driel & Berry, 2012). I also examined research on the impact of educational reform (Lee & Yin, 2011; Lee et al., 2013; Van Veen et al., 2005), cognitive, social, and emotional processes (Beauchamp & Thomas, 2009; Yuan & Lee, 2015), stress (Timoštšuk & Ugaste, 2012; Van Veen & Sleegers, 2006; Zembylas, 2003a, 2003b), and efficacy (Bandura, 1994, 1997; Tschannen-Moran et al., 1998, 2007) has on teacher development. However, my review revealed very few studies that explored motivations to teach, and concurring with Yuan and Lee (2015), it was clear that work relating to how pre-service teachers construct their identity was an area still largely unexplored.

3.3 Settling on a Research Question

As I settled on my topic, further investigations revealed even fewer studies that explored both motivations to teach and the relationship between personal beliefs and teaching behaviours.

Hence, within the context of the challenges outlined, I wanted to understand not only what it is that motivated people to become teachers of STEM-related disciplines, but to be better able to understand how perceptions and experience-related beliefs influence the formation of pre-service identities, with the eventual outcome of being better able to support those entering the teaching profession; to support their induction, improve teacher retention, and ultimately improve the learning experiences of children and young people. As such it was this curiosity that led to the formulation of my research question:

What influence do the meanings assigned to previous learning experiences, including personal perceptions of subject knowledge, have on the formation of design and technology pre-service teacher professional identity?

3.4 Designing a Robust Study

Having established an area for my work, my next step was to design the study and for me a big part of this was working out my own position. As someone who loves teaching and working within STEM, I needed to figure out what were my motivators?, What were my beliefs?, and then how in exploring this topic, I could use my experience of working and teaching within the field to best effect yet do so without influencing/avoid manipulating the outcomes of the study.

Next, I began to explore potential theoretical frameworks. To help ensure congruence between my ontological and epistemological position, I found myself leaning toward the philosophical field of symbolic interactionism. Within the context of my study, symbolic interactionism was perfect because I recognised that it would help me to explain how an individual's identity forms, following reflection on their interactions with others, especially those who have had a significant influence on their lives (Mead, 1934). Specific to my study this was particularly important because from the perspective of pre-service teachers, whose identities are '*deeply embedded in their personal biography*' (Bukor, 2015: 305) research suggests that those learning to teach enter teacher education programmes '*Looking backward on their years of school experience and project it into the present*' (Britzman, 2007: 2).

Having chosen my theoretical approach, I then moved to explore the methods I could use to undertake my research. In designing this aspect of my study, I concluded that my participants would need to be pre-service teachers at the very start of their teacher education programmes drawn from the fullest range of STEM-related subject disciplines: Mathematics, Biology, Chemistry, Physics, Computer Science, and Design and Technology (including Engineering). However, aware that based upon what they may reveal during interviews I may need to gather additional data to explore their responses more fully, I was cognizant that there could be advantages in speaking to them during or toward the end of their training. Therefore, in designing the study I sought a method that, based upon emergent findings, would allow me to go back and conduct further investigations if necessary.

During the preliminary stages of my Ph.D., I was fortunate to have been encouraged to explore a range of methods and methodologies, and because it also aligned with my ontology and the type of research I was seeking to undertake, an approach informed by Grounded Theory appeared to be the perfect choice. Aware of several nuances within this method, again based on what I believed would help me to secure the richest data, I chose to follow an approach informed by Constructivist Grounded Theory (CGT) (Charmaz, 2006, 2014). For my study this was an advantage because CGT draws upon both inductive and deductive theory generating procedures, the result being that theoretical concepts are constructed, rather than being 'discovered,' with the reasoning being undertaken after analysis of the data.

As an approach it enabled me to consider all possible theoretical outcomes, rather than forcing one to emerge. Given my interest in, and experience of the field this was crucial in helping me to use my experience while at the same time serving as an important strategy to help mitigate the potential for bias. Throughout my research I also embraced the notion of reflexivity, which helped sensitise me to emergent issues within the data, which helped to support me in the construction and generation of my research findings. So, embracing methods advocated by Bryant and Charmaz (2007) and Charmaz (2014), I undertook a tightly scheduled programme of concurrent data collection and analysis, with emergent outcomes from one data set informing the subsequent research phase. In gathering data, I took great care to ask exploratory, rather than interrogative questions, and during analysis I used coding procedures advocated by Glaser (1992) and Charmaz (2014).

3.5 My Participants

In total my study engaged 78 participants. At the time of their engagement each was following a teacher education route to become a secondary age phase (children aged between 11 and 18 years old) teacher of a STEM-related subject discipline. Prior to participation the aims and purpose of my study were explained, and informed consent was obtained. Data collection took the form of semi-structured interviews, with follow-up email discourse where necessary. Interviews were undertaken in accordance with procedures advocated by Bowden and Green (2005), recorded and transcribed verbatim, with care taken to accurately record responses to avoid misrepresentation. I always ensured that interviews took place in a neutral setting, at a time convenient to the participants, and always adhering to ethical guidance outlined by the British Educational Research Association (BERA, 2018).

Due to the phased approach to research collection that grounded theory allows, I was able to engage participants at all stages of their training (so from those just a couple of weeks into the training, to those who had recently graduated) which helped me to gain access to rich research data. Then toward the end of my study I held a series of small focus groups which were designed to help not only triangulate but to validate the study's findings.

3.6 Gathering Data

Beginning each interview by posing questions that sought to establish my participants' recollections of being taught as a pupil and how they thought they learned best, during the later phases of questioning I sought to establish how my participants perceived the meaning they had assigned to their experiences as learners, and how they thought they could or would influence them as they themselves became teachers. Participants were able to recall numerous experiences of learning. Pleasant memories (positive experiences) were of 'good teachers and good teaching,' and unpleasant recollections (negatively recalled experiences) included accounts of poor teachers and bad teaching. I began by unpicking their recollections and sought to establish what they meant by 'good and bad' teachers and teaching. Good teachers were cited as having patience, tolerance, approachability, and enthusiasm, with good teaching being demonstrated by strong subject knowledge and an ability to explain things easily. Pleasant experiences frequently related to practical activities, undertaken by confident teachers, who were unafraid to take a risk, and who explored a range of teaching strategies.

In recalling pleasant memories participants described wanting to emulate their favourite teachers, both in attitude and pedagogical approach. In these instances, the impact on the learner (their recollection of learning as experienced as a pupil) and learning was overwhelmingly positive, with participants talking about enjoyment, taking ownership of the work, developing a passion for the subject, personal development, and growth in confidence. Conversely, in recounting their experiences of 'bad teaching' undertaken by poor or lazy teachers, I witnessed countless examples of the damage poor teaching had on motivation and detrimental impact on learner confidence.

Following initial analysis, as I moved from open to selective coding, I realised I needed to gather more data to help me to dig deeper to unearth my understanding of how, as they moved through their teacher training programmes, their experiences as learners (good or bad) were shaping their development as teachers of STEM, so was incredibly pleased that I had chosen an approach that drew upon grounded theory for my investigations.

3.7 What I Found Out

At the end of this initial phase, irrespective of their age, gender, or STEM-related subject discipline, in recalling their memories of learning analysis, my participants' responses showed that 'subject knowledge' was a constantly reemerging theme. Hence during the subsequent research phases I sought to discover participants' perceptions of the impact subject knowledge had on their experience as a learner, and then going forward, on their development as a teacher.

Within my study, participant perceptions of poor teaching were associated with weak subject knowledge and a belief that '*weak subject knowledge limits the range of teaching styles.*'

Participants perceived that where a teacher lacks adequate subject knowledge, they are likely to spend their time filling their subject knowledge gaps, rather than focussing on effective ways to deliver knowledge to learners. Another perception raised was the impact of poor pedagogical adaptation, this is where subject knowledge is delivered unrefined, with little or no consideration of how knowledge is received by the learner. In this instance pre-service teachers believed that those with weak subject knowledge were more inclined to deliver lessons which were procedural, and reliant on pupils following rules which ignore the development of conceptual understandings. Under these conditions, participants perceived those teachers were more likely to '*stick to a simple activity and the lesson is teacher led board and textbook work.*' The impact of weak subject knowledge on identity formation and the mental health of the teacher was also raised as a concern. With participants perceiving that '*weak subject knowledge undermines you, erodes your confidence and can really have a detrimental impact on your own self-esteem.*' Conversely, good teaching was associated with strong, confident teachers in command of a solid knowledge base '*… teachers with stronger subject knowledge are more motivated and confident. If a student is getting it wrong, they can strip the problem down to its basics to explain it several different ways until the student understands.*'

At this stage analysis of the data illuminated several themes worthy of further discussion, however, for the purposes of this chapter I will articulate those which relate to how my participants' perceptions of the impact of a perceived deficiency in subject knowledge play in limiting the development of identity. According to Shulman (1986), there is '*a growth in knowledge of teaching*' specific to the process of converting subject matter for the purposes of teaching. Commonly known as Pedagogical Content Knowledge (PCK), this is a special type of knowledge that only teachers have and is the process where a teacher transforms specialist knowledge of their subject discipline into content suitable for effective pedagogical dissemination (Shulman, 1986, 1987).

However, it struck me that what if, during the process of training, the pre-service teacher perceives that their knowledge is limited, and they do not have enough specialist subject knowledge to transform? What is the impact of a '*subject knowledge gap*' on pedagogy? and on the formation of an individual's identity as a teacher?

3.8 The Impact of Anxiety

While training to teach, it was clear that pre-service teachers encounter many experiences that have the potential to cause concern; however, analysis identified that there is a specific type of anxiety around a lack (or perceived lack) of subject knowledge, and findings show that the impact of weak subject knowledge on a pre-service teacher's development is significant. My findings show that if, during training, the pre-service teacher's subject knowledge is deficient (as perceived by the individual), then their ability to adapt subject matter for the purpose of teaching is compromised. At the liminal moment when subject matter should become PCK (Pedagogical Content Knowledge), if the pre-service teacher's subject knowledge is deficient (perceived or real), this creates a '*gap*' in the space where one's identity as a teacher is formed, which has the potential to limit personal development and subsequently restrict the formation of the teacher's professional identity.

3.9 Learning to Teach When You Do Not Know What It Is That You're Teaching!

Where a pre-service teacher does not have the subject knowledge from which to draw, they struggle to know what they are teaching or why they are teaching it. It is this lack of subject knowledge that prevents the pre-service teacher from developing the ability to transform subject matter into pedagogical content to make knowledge accessible to a learner. Under these conditions, the pre-service teacher encounters increased levels of emotional anxiety often manifested as an inability to cope. This impacts negatively upon an individual's ability to fully form a strong professional teacher identity and in turn to develop strong self-efficacy. These feelings (of anxiety) have the potential to undermine an individual's confidence, *leading to* low teacher efficacy. Taken as an extract from the wider findings of my thesis, Fig. 3.1 illustrates the correlation in and between these phases of my study's outcomes.

During training, the absence of strong subject knowledge prevents the pre-service teacher from having the fullest opportunity to learn to teach. Where the pre-service teacher may be preoccupied with learning subject knowledge, they are unable to focus fully on developing their pedagogical skills as a teacher. This is likely to lead to an inability to be innovative, to push personal boundaries, or to take risks, resulting in pedagogical decisions based not on the learning needs of learners but on their needs to keep safe, to maintain control and manage the behaviour of the class. Once training ends, as qualified teachers, they are unable to move safely beyond '*survival*' (Le Maistre & Paré, 2010), and seek to stay within their comfort zones, and hence work to create situations where they maintain control. In turn, pupils' learning is restricted, in that it does not go beyond the teachers' own prepared knowledge. Consequently, they (the teachers) prevent themselves from developing and engaging in sound pedagogical approaches to lesson delivery, which subsequently prevents them from delivering high-quality teaching.

Over the course of my study this original line of enquiry led to subsequent data collection phases, and the emergence of several other outcomes. Within the limitations (wordage) of this chapter there is not sufficient scope to address them in fine detail. However, further to the discussion already presented relating to the impact 'weak' subject knowledge has on an individual's development, subsequent data collection phases and their analysis led to discussion around what happens when

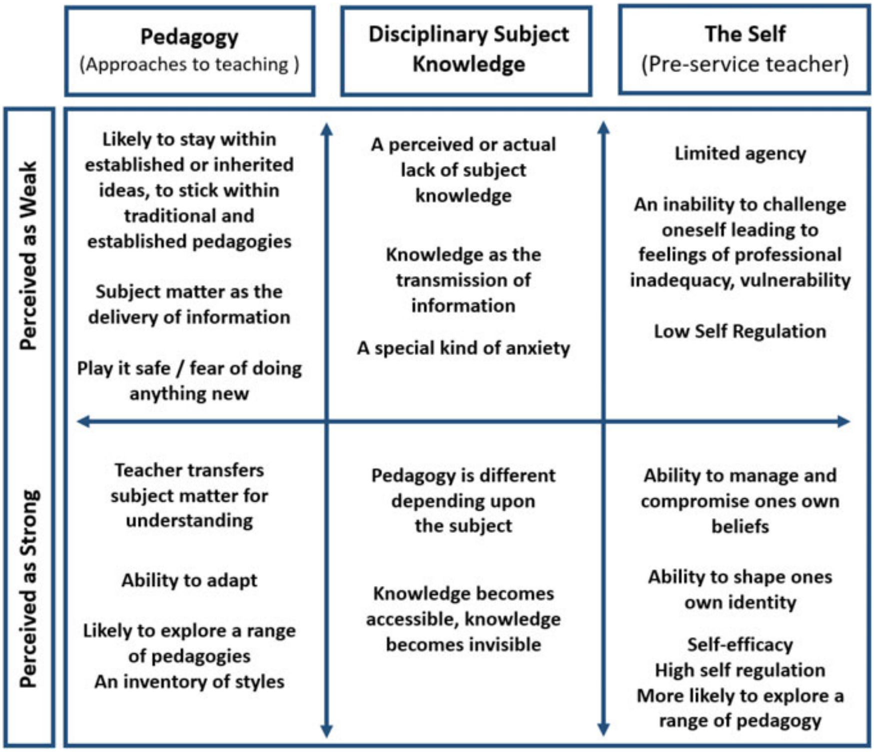

Fig. 3.1 The subject knowledge gap: impact on pedagogy and identity (adapted from Irving-Bell, 2018)

a pre-service teacher is unable to effectively challenge their perceptions of '*what a teacher should be*,' how a teacher should act or behave. Enquiry that led to the development of the original concepts of unintentional self-sabotaging behaviours, which in turn led to the conceptual notion of identity drift.

So, after years of study, as analysis of my research shows when an individual perceives they have a gap in their subject knowledge, that weakness, perceived or real, has the potential to limit their pedagogical development. This is significant because typically, in comparison to some other subject areas, work within the STEM-based disciplines demand the teacher have a strong working knowledge of, breadth of understanding, coupled with a diverse range of practical skills across a wide range of multi-disciplinary areas. This is a potential issue because rather than drawing on innovative pedagogies and utilizing student-centred approaches, individuals are more likely to adopt teacher-focussed methods. In turn this is likely to lead to the adoption of constrained teaching styles as the teacher seeks to stay within their pedagogical safe space. In these instances, research shows that teaching is more likely to be reduced to the delivery of knowledge, which according to Trigwell et al. (1999) is, in turn, more likely to result in the learner's adoption of surface approaches to their own learning.

My research shows that personal beliefs have the potential to impede an individual's ability to develop a strong professional identity. Where deficiencies in subject knowledge are perceived, those difficulties are amplified, particularly during the preliminary stages of a teacher's development. The result is a constrained ability to establish a keen sense of self, which is vital to help ensure that teachers new to the profession are equipped with sufficient pedagogical competence and confidence. Confidence that enables them to cope effectively with the constant challenges and changes a career in teaching will inevitably bring. Successful and sustained teaching is the careful negotiation and constant compromise of one's own (quite often) deep-seated views, values, opinions, and beliefs. However, where the teacher struggles to effectively manage their beliefs the result can create a condition where the individual is unable to develop fully as a confident, autonomous practitioner. In the STEM classroom (pedagogically) this manifests as teacher-led, formulaic, less than engaging lessons. The lack (perceived or real) of disciplinary expertise has the potential to restrict the teacher's engagement with new and emerging technologies. In the longer term the impact of these struggles can lead to unintentional self-sabotaging behaviours and drifting professional identities where the ultimate consequence is likely to be attrition (Irving-Bell, 2018).

Before moving to explore how this might be used to improve teaching and learning it may be useful just to define, briefly what I mean by '*unintended self-sabotage*' and '*identity drift*.'

3.10 Self-sabotaging Behaviours

Self-sabotaging behaviour defines the occurrence where unintentionally during their training the pre-service teacher sabotages their own professional development, the result being they unintentionally incapacitate their own progress. At a fundamental level, '*self-sabotage*' occurs where the individual is unaware of or unable to challenge their own experience-related beliefs. Their personal narratives, the stories they tell themselves, and how they negotiate their interpretation of society's view of '*what a teacher should be.*'

With respect to their emotional state, self-sabotaging behaviours are likely to manifest in negative feelings. Feelings that include uncertainty and of being powerless. Subsequently these feelings of anxiety are likely to lead to the lowering of the individual's teacher's self-esteem. Developed from my research a taxonomy of self-sabotaging behaviours evolved. The taxonomy presents five stages ranging from *unaware*, where there is no conscious awareness by the individual that their actions, attitudes, or behaviours are potentially contributing to the sabotage of their own professional development, through to *rigid*, where the individual is unable or unwilling to move from their established views and beliefs, to challenge their personal philosophy, ideology, or opinions of how a teacher should be, act, or behave.

My findings show that deep-rooted personal philosophies, unrealistic ideologies, or naïve expectations are likely to be significant contributory factors in '*self-sabotaging behaviours.*' Having assigned meaning to their own experiences, only once an individual has recognised the '*mismatch*' between their beliefs and the reality of their nascent practice, will they be aware of the potential need to '*modify*' their fixed ideas (beliefs) and only then may new (different) professional practices emerge. This process involves the constant negotiation between one's own ideology, personal philosophy, and the reality of professional practice.

3.11 Identity Drift

Again, for clarity, emergent from my study identity drift describes and as such is defined as the instance where an individual's ideological values and beliefs and the reality of their classroom practice become unaligned. Here the individual is unable to reconcile their internalised identity from their external one. Both outcomes, self-sabotage and identity drift have the potential impact (over time) to lead to teacher attrition.

3.12 So How Might the Outcomes from My Study Be Useful to You?

My research found that teachers' behaviours are influenced by their underlying beliefs, values, and attitudes, and unless that teacher is convinced of the need to alter their approach, they will avoid adapting their practice. Fortunately, I also discovered that identity is not a fixed trait; it is continually shaped and re-shaped in response to new experiences and from this process new meanings can be made considering an individual's reinterpretation of past, and interpretation of current events.

However, because notions of identity, and personal integrity are intertwined with our professional practice, to have a better understanding of ourselves, both the personal and the professional self must be considered when we reflect upon our identities as teachers.

It was at this phase in my work that I became aware of '*The Courage to Teach*' where Palmer (2007) explores the notion of an 'undivided life.' According to Palmer teachers who are passionate about teaching share a similar trait, namely that '*a strong sense of personal identity infuses their work*' (Palmer, 2007: 11). According to Palmer when that identity is lost, teachers become internally divided from why, who, and what they teach. In his work Palmer provides a framework that can be used to encourage the journey toward an undivided life. Within this we are asked to consider what we do not know, question what we do know, and to push for the discovery (outcomes) to be valued, attending '*to the inner teacher not to get fixed but* *to befriend the deeper self, to cultivate a sense of identity and integrity that allows us to feel at home wherever we are*' (Palmer, 2007:33).

3.13 But What Does This Mean in Practice, for Your Practice?

Well, if you have ever been required to deliver content beyond your area of expertise and were feeling a little anxious or hesitant about it you now know that this was a perfectly normal reaction! But moving forward, should a similar request be asked of you in the future, how might you use the outcomes of this research to support your decision-making approaches to overcome the potential challenges when faced with the navigation of an unfamiliar curriculum?

Developed from my research, influenced by Palmer and in conjunction with my emergent understanding of the use of autoethnographic reflection as a tool for self-development, in the next section I present some ways that outcomes from my study may be useful to you. In supporting the development of not only your practice but also potentially for you in work you may undertake to support colleagues, or those new to the profession you may be working with.

3.14 Research Suggestions for Teachers: Developing the Capacity to Become Comfortable

To practice this reflective task, you need nothing more than something to write or draw with, something to write or draw on, and a few minutes in an appropriate space with your thoughts.

Reflecting on your own situation, think about a topic you are comfortable with and have delivered successfully in the past. Which pedagogies did you use? How did you interact with learners? Now think about a subject area you are less familiar with. Consider how you think you would deliver a lesson compared to how you would deliver the same lesson if you were more comfortable with the subject matter. Is there a difference? and if so, aside from how being in this situation would be likely to make you feel, consider the potential impact on the learners and their learning.

Now, considering your context ponder strategies that may be useful to support yourself. Are you able to find a mentor who could help you to gain confidence in developing your expertise in this area? Or team teaching is feasible? Maybe you could share a skill with a colleague, and in return you could support them in developing an area of their practice? Alternatively, drawing directly upon your strengths and your established pedagogical expertise, you may decide to off-set your limited knowledge of this area and decide to create an experiential classroom where you learn alongside your students. Using this simple scaffold, coupled with these prompt questions, apply the same process as outlined above to support you in addressing these or similar challenges you may have or be facing:

- As the result of curriculum change, or staffing challenges, how could you use this scaffold to help you to manage gaps in your own subject knowledge?
- Has there been an occasion where your personal teaching-related beliefs have been in conflict with your professional self? What steps could you take to resolve your struggle and what would the impact be on your professional identity?

Having identified the challenges of self-sabotage and the notion of identity drift, many of my ideas to support STEM teachers to reclaim the power of their agency are drawn from mindfulness-based interventions. For more ideas of how you may support the strategic development of your work in this area please see Hugh-Jones et al. (2018). For further reading around the co-creation of learning and teaching see Bovill's paper (2020) will signpost you to additional resources.

3.15 Supporting the Development of Others (to Develop) a Robust Professional Identity

Having shared some ideas that, you can use to reflect upon your own practice, the next section focusses on how you might use findings from my research, in conjunction with your own experiences to support the development of others. This may include those you line manage, pre-service, or those teachers in the early phase of their STEM teaching careers. Like the previous task, this is a practical desk-based activity you may use to support a colleague.

It is designed to boost confidence, efficacy, and motivation. This is a little different in that you are working with colleagues, so I have provided a couple of examples, but the process is the same:

Example One:

You are working with a recently qualified colleague to unpick an aspect of their experiential practice that may be supporting a self-sabotaging behaviour; a behaviour that in the longer term may prevent identity drift, and subsequently help reduce attrition.

Example Two:

You are working with a pre-service teacher whose lack of confidence is limiting their pedagogical development and constraining their teaching.

In both examples in conjunction with my research Fig. 3.2 illustrates how you might encourage movement beyond the individual's pedagogical safe space as a mechanism to support the development of not only their practice but their identities as teachers.

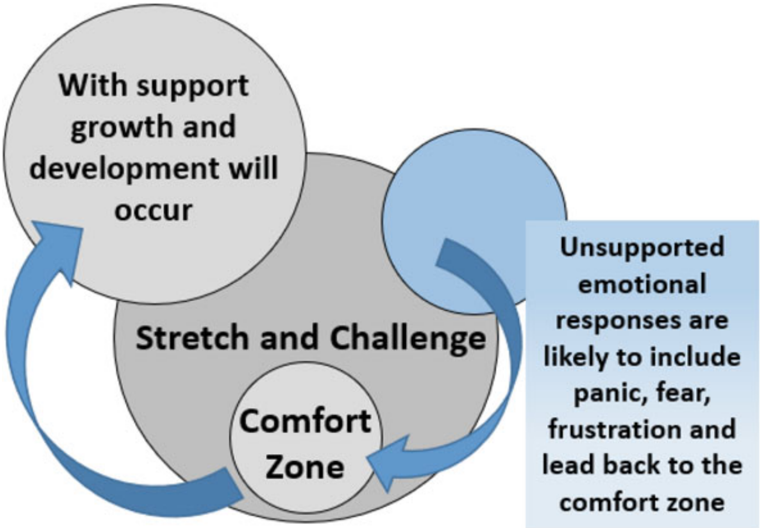

Fig. 3.2 Mentoring beyond the comfort zone (Irving-Bell, 2019)

My study discovered that for some STEM teachers the biggest step they took during their teacher education programme was recognizing that their personal, often deeply held beliefs, were counterproductive to their development. Acknowledgement however is only the first step and challenging one's preconceived ideas about STEM learning and teaching is just the beginning of what for some can be a difficult and arduous journey. So, before you undertake any work to support colleagues you need to do your utmost to create an environment where those you are seeking to support feel sufficiently confident to be able to engage in honest and open self-reflection with you. This will involve creating a space where they feel safe to challenge aspects of their practice, including the recognition that their personally held experience-related beliefs, about teachers and teaching, that may be sabotaging their development.

Developed from my research (Irving-Bell, 2018), but also drawing upon guidance offered to support pre-service teachers to engage in risk-taking in the classroom (Irving-Bell, 2019) these prompts are designed to help you:

- Do not wait for an issue to arise to begin offering support! If you can work to create an open environment of collaborative learning and sharing. This way you can tackle challenges before they become insurmountable, and if challenges do become issues when offered help your colleague is more likely to recognise the offer comes from a place of care and be more open to accepting support.
- This is going to be difficult be mindful to meet at a time that gives you enough time and space to discuss. For example, not at the end of a full day's teaching.
- If you have invited your colleague for a chat, be clear to share the purpose of a meeting, but try not to drive the agenda. Be a good listener. During the conversation

encourage your colleague to identify potential areas for personal growth and development.
- Be prepared to undertake some work yourself. For example, to scaffold them in their practice to be able to enable them to take risks without fear of failure.

3.16 Concluding Thoughts: How This Research Could Be Developed Further

When I undertook my research, naïvely I thought the outcome would be the development of a pedagogical framework that teachers could use them to support them in the effective delivery of STEM and the STEM-related subject lessons. However, my work led me into unfamiliar territory, and I very quickly found myself out of my comfort zone, exploring identity and what it means to be a 'teacher.'

After several years of exploration, which was peppered with self-doubt, frustration, and anxiety that my work would ever come to meaningful conclusion, I was and still am fascinated by how an individual's experience-related beliefs influence their decision to become a teacher of a STEM-related discipline, and subsequently how it impacts upon their development during the teacher education process. Not only in terms of their own approaches to their own learning but how that in turn influences how they teach.

A teacher's beliefs are shaped by their sociocultural background, their memories, life and work experiences, and my research shows that personal narratives, the meanings STEM teachers in training have assigned to their past experiences, play a key role in the formation of their emergent professional identities as teachers. How an individual approaches their learning, responds to, and subsequently assigns meaning to new experiences is inextricably bound to meanings they assigned to experiences of the past. This is significant for those working within the STEM disciplines because of the multi-faceted, fluid nature of the subject and it is important that we ensure we support those teachers who may be tightly bound to traditional pedagogy to embrace new technologies and their associated learning and teaching approaches.

According to Beauchamp and Thomas shifting identity is a difficult process, and '*fundamental changes in teacher identity do not take place easily*' (Beauchamp & Thomas, 2009:185), and within the context of this chapter this is of particular importance because when encountering difficulties in the classroom teachers have a tendency to '*fall back on their traditional memories of how to teach*' based upon experiences from when they were students (Hargreaves, 2010:146).

If there is one thing that I would hope that you take away from having read this abridged version of my thesis is that no one enters our profession with the deliberate intention of becoming a 'bad' teacher. I believe this and have found that when working to support others, irrespective of their years in service (but especially when working with those new to the profession), built around my findings, you can create frameworks that support an individual's reflection on and development of their professional teaching and learning practice.

Frameworks that can help individuals to become aware of and as such avoid potentially damaging self-sabotaging behaviours, behaviours that may lead to identity drift and fuel their decision to leave the teaching profession.

References

Bandura, A. (1997). *Self-efficacy: The exercise of control*. W. H. Freeman.

Bandura, A. (1994). Self-efficacy—Encyclopaedia of human behaviour. *Academic Press, 4*, 71–81.

Beauchamp, C., & Thomas, L., (2009). Understanding teacher identity: An overview of issues in the literature and implications for teacher education. *Cambridge Journal of Education*, *39*(2), 175–189. Research Papers in Education 489.

Bovill, C. (2020). Co-creation in learning and teaching: The case for a whole-class approach in higher education. *Higher Education, 79*, 1023–1037. https://doi.org/10.1007/s10734-01900453-w

Bowden, J. A., & Green, P. (Eds.). (2005). *Doing developmental phenomenography*. RMIT University Press.

British Educational Research Association [BERA]. (2018). *Ethical guidelines for educational research* (4th ed.). Retrieved December 28, 2020, from https://www.bera.ac.uk/researchers-resources/publications/ethicalguidelines-for-educational-research-2018

Britzman, D. P. (2007). Teacher education as uneven development: Toward a psychology of uncertainty. *International Journal of Leadership in Education, 10*(1), 1–12.

Bryant, A., & Charmaz, K. (2007). Grounded theory in historical perspective: An epistemological account. In A. Bryant & K. Charmaz (Eds.), *The SAGE handbook of grounded theory* (pp. 31–57). Sage.

Bukor, E. (2015). Exploring teacher identity from a holistic perspective: Reconstructing and reconnecting personal and professional selves. *Teachers and Teaching, 21*(3), 305–327. https://doi.org/10.1080/13540602.2014.953818

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Sage.

Charmaz, K. (2014). *Constructing grounded theory. A practical guide through qualitative analysis*. Sage.

Day, C., Kington, A., Stobart, G., & Sammons, P. (2006). The personal and professional selves of teachers: Stable and unstable identities. *British Educational Research Journal, 32*(4), 601–616.

Glaser, B. G. (1992). *Basics of grounded theory analysis*. Sociology Press.

Hargreaves, A. (2010). Presentism, individualism, and conservatism: The legacy of Dan Lortie's schoolteacher: A sociological study. *Curriculum Inquiry, 40*(1), 143–154. https://doi.org/10.1111/j.1467-873X.2009.00472.x

Irving-Bell, D. (2018). *The formation of science, technology, engineering and mathematics teacher identities: pre-service teacher's perceptions*. Lancaster University. Retrieved December 28, 2020, from https://doi.org/10.17635/lancaster/thesis/404

Irving-Bell, D. (2019). Risk taking in the classroom—Moving teachers forward from pedestrian to innovative practice. In *Mentoring design and technology teachers in the secondary school: A practical guide* (1st ed., pp. 142–153). Routledge. https://doi.org/10.4324/9781351011976-12

Lee, J. C. K., & Yin, H. B. (2011). Teachers' emotions and professional identity in curriculum reform: A Chinese perspective. *Journal of Educational Change, 12*(1), 25e46.

Lee, J. C. K., Huang, Y. X. H., Law, E. H. F., & Wang, M. H. (2013). Professional identities and emotions of teachers in the context of curriculum reform: A Chinese perspective. *Asia-Pacific Journal of Teacher Education, 41*(3), 271e287.

Le Maistre, C., & Paré, A. (2010). Whatever it takes: How beginning teachers learn to survive. *Teaching and Teacher Education, 26*(3), 559–564.

Lindblom-Ylänne, S., Trigwell, K., Nevgi, A., & Ashwin, P. (2006). How approaches to teaching are affected by discipline and teaching context. *Studies in Higher Education, 31*(3), 285–298. https://doi.org/10.1080/03075070600680539

Lortie, D. C. (1975). *Schoolteacher: A sociological study*. University of Chicago Press.

Mead, G. H. (1934). *Mind, self, and society*. University of Chicago Press.

Palmer, P. J. (2007). *The courage to teach: Exploring the inner landscape of a teacher's life*. Jossey-Bass.

Prosser, M., & Trigwell, K. (1999). *Understanding learning and teaching. The Experience in Higher Education*. Open University Press.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1–22.

Timoštšuk, I., & Ugaste, A. (2012). The role of emotions in student teachers' professional identity. *European Journal of Teacher Education, 35*(4), 421–433. https://doi.org/10.1080/02619768.2012.662637

Trigwell, K., Prosser, M., & Waterhouse, F. (1999). Relations between teachers' approaches to teaching and students' approaches to learning. *Higher Education, 37*, 57–70.

Tschannen-Moran, M., Hoy, A. W., & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of Educational Research, 68*(2), 202–248.

Tschannen-Moran, M., Hoy, A. W., & Hoy, W. K. (2007). The differential antecedents of self-efficacy beliefs of novice and experienced teachers. *Teaching and Teacher Education, 23*(2007), 944–956.

Van Driel, J. H., & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. *Educational Researcher, 41*(1), 26–28. https://doi.org/10.3102/0013189X11431010

Van Veen, K., & Sleegers, P. (2006). How does it feel? Teachers' emotions in a context of change. *Journal of Curriculum Studies, 38*(1), 85e111.

Van Veen, K., Sleegers, P., & van de Ven, P. (2005). One teacher's identity, emotions, and commitment to change: A case study into the cognitive-affective processes of a secondary school teacher in the context of reforms. *Teaching and Teacher Education, 21,* 917e934.

Yuan, R., & Lee, I. (2015). The cognitive, social and emotional processes of teacher identity construction in a pre-service teacher education programme. *Research Papers in Education, 30*(4), 469–491. https://doi.org/10.1080/02671522.2014.932830Y

Zembylas, M. (2003a). Emotions and teacher identity: A poststructural perspective. *Teachers and Teaching, 9*(3), 213–238.

Zembylas, M. (2003b). Interrogating 'teacher identity': Emotion, resistance, and self-formation. *Educational Theory, 53*, 107–127.

Dawne Irving-Bell is a Reader and Senior Learning and Teaching Fellow at Edge Hill University, a Principal Fellow of the Higher Education Academy, CATE2020 Award Winner and recipient of a National Award recognising her outstanding contribution to Teacher Education. With a passion for visual thinking and technology education, she established 'The National Teaching Repository', edits the Journal of Social-Media for Learning, and co-leads the facilitation of Teaching Fellowship work on behalf of the International Society for the Scholarship of Teaching and Learning (ISSOTL).

Chapter 4
Exploring Teachers' Perceptions and Strategies for Curriculum Practice in Technology Education

Elizabeth Reinsfield

Abstract In New Zealand, the technology curriculum can be positioned to expose students to future-focussed learning. The subject affords opportunities for pedagogical practice to be responsive to student interests and focussed on technological-related issues and societal needs, in a variety of learning contexts and technological areas. This chapter is derived from qualitative research, which uncovered new knowledge about the nature of technology education for six secondary teachers in New Zealand, using a combination of interpretive, sociocultural, and case study methods. Data relied on several primary sources, including the New Zealand Curriculum and its supporting materials, two or three semi-structured interviews per participant, lesson observations, department meetings, teacher reflections, and teacher-generated resources. The findings confirmed that there was disparity between some teachers' perceptions of the nature of technology education, and their emerging practice. Recommendations are made to advocate for strategies that assist teachers to develop new understandings and foster an environment that prioritise learners' innovative thinking and future-focussed technological outcomes. There is a particular focus on aspects of curriculum practice that will support teachers to navigate the thresholds of understanding that they might find troublesome and to facilitate a transformation in both thinking and practice in technology education.

Keywords Curriculum · Pedagogical practice · Perceptions · Thresholds of understanding

4.1 Introduction

Notions of citizenship, students' academic development, occupational preparedness, as well as social and economic outcomes are all drivers for a school-based curriculum (e.g., Adler, 1982; Reinsfield, 2020; Tyack, 1988). Technology education in New Zealand (Ministry of Education (MoE), 2007, 2017) has experienced significant

E. Reinsfield (✉)
University of Waikato, Hamilton, New Zealand
e-mail: elizabeth.reinsfield@waikato.ac.nz

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_4

conceptual change over time and is heavily influenced by governmental agenda, community expectations, and teachers' differing perceptions of the purpose of the subject (de Vries & Mottier, 2006; Jones, 2009; Jones & Carr, 1992; MoE, 2014; Reinsfield, 2014, 2018). The role and status of technology education have evolved, but its cross-disciplinary nature means that there is no single theoretical perspective that can define it (Pacey, 1992). This paradox presents a confusing climate for some technology teachers and can provide insight into how teachers navigate the challenges, or thresholds of understanding, for their professional practice.

Technology education yields unique opportunities to engage students in their learning through both practical and innovative means. This notion is of interest in a climate where teachers are expected, according to the curriculum requirements, to foster creative and critical thinking and develop students' practical skills (MoE, 2007, 2017). Teacher perceptions and the dominant discourse within a teaching community, however, influence the way that professionals interpret, make meaning, and develop their professional identity or practice (Dakers, 2006; de Vries, 2005; Fox-Turnbull & Sullivan, 2013; Hoyle, 2008; Kadi-Hanifa & Keenan, 2016; MacGregor, 2017).

As part of their professional practice, technology teachers are required to make meaning of curriculum concepts for their specialist area (e.g., digital technology and processing technology), with a view to enact teaching methods that support problem-based learning and are responsive to student needs. Some teachers of technology can find this process difficult and can be regressive or indifferent to the enactment of the curriculum (Jones et al., 2004; Mansellet al., 2001; Paechter, 1995). Further, some technology teachers communicate historical understandings of the nature of technology education (Jones & Compton, 2009; Jones et al., 2013; Reinsfield, 2012; Williams, 2009).

4.2 The Questions I Asked and Why They Are Important

Technology teachers' perceptions and attitudes towards the nature of the subject can be strongly embedded and align with a view that content should focus on "design and make" activities (Williams et al., 2015, p. 2). In this case, a practitioner's focus might emphasise the teaching of practical skills, which might be to the detriment of students developing critical, creative, and informed thinking processes. Teachers' evolving knowledge for practice, in relation to their curriculum understandings, can also be shaped in culturally meaningful ways (Hill, 2003). Interest in the perceived disparity between theory and practice in technology education led to the overarching question:

> How do technology teachers' perceptions influence their interpretation and enactment of Technology in the New Zealand Curriculum? (MoE, 2007).

The ways that teachers of technology use their lived experience to make meaning of the curriculum is *key* to the enactment of their teaching practice. The sub-questions designed to explore this notion were:

How do teachers *interpret* the concepts presented within the official technology curriculum? (MoE, 2007).

How do teachers *enact* the concepts presented within the official technology curriculum? (MoE, 2007).

4.2.1 Thresholds of Understanding

To transition from interpretation to enactment, teachers navigate differing thresholds of understanding, which depend on their perceptions of and experience with technology education. A threshold concept can be used as a means of providing a new or transformed way of interpreting something and can represent how people perceive their subject (Meyer & Land, 2003, 2006; Reinsfield, 2018). There are characteristics that define threshold concepts, which,

> Should be transformative … difficult to unlearn and inherent to understanding within a particular phenomenon … should be bounded, and enable the critique of past understandings, to challenge individual's own thinking processes … can also enable educational change, through the development of a new conceptual space (Meyer & Land, 2005, pp. 373–374).

Alongside these characteristics is the notion of troublesome knowledge, which can limit or moderate teachers' learning and practice and because of engagement with innovative ideas provide a deeper understanding of the conceptual processes that enable interpretation and enactment of the technology curriculum (Meyer & Land, 2005). The concepts that teachers find troublesome can be explained through the notion of liminality. Liminality aids the understanding of the transitional space within which teachers' thinking can evolve. Such a conception also acknowledges that there may be a threshold where individuals *might* be unable or unprepared to achieve a transformed status (Meyer & Land, 2003). According to Meyer et al. (2008), a teacher's way of knowing (episteme) can be the crucial factor to a change in practice.

4.3 How I Tried to Answer the Questions

There were four phases of research, designed to address the research questions. In the first three phases, data were collected from semi-structured interviews, lessons and department meeting observations, and teacher-generated resources. The final phase explored the nature of technology education, as represented by the case studies of two secondary schools. An overview of the data collection process, with links to the research questions, is summarised in Table 4.1.

Table 4.1 Summary of the research process

	Research question	Data collection method
Phase one: Teachers' perceptions	How do technology teachers' perceptions influence their enactment of the New Zealand curriculum?	An initial semi-structured interview of approximately 40 min Observation of department meetings
Phase two: Interpretation of the curriculum	How do teachers interpret the concepts presented within the official technology curriculum?	Observation of department meetings Teacher generated resources
Phase three: Enactment of the curriculum	How do teachers enact the concepts presented within the official technology curriculum?	Lesson observation of one class or block, for between 45 min and one hour
Phase four: Developing the case studies		

4.4 What I Found Out and How This Might Be Used to Improve Teaching and Learning

The findings indicated there are persistent tensions that continue to influence technology teachers' pedagogical practice, which include a propensity for teachers to emphasise practical skills and knowledge over the development of students' creative or critical thinking for the development of innovative outcomes. Five of the six participant teachers communicated their understanding of the subject's potential in relation to problem-solving, innovative, and authentic learning. All teachers indicated their school's organisational structure, community understandings of the curriculum, and perceptions regarding the purpose of technology were affecting their practice. The findings from each phase are discussed next.

4.4.1 Phase One: Teachers' Perceptions

Participants were asked for their opinions about teaching in the technology education community in New Zealand. They described their perceptions based upon professional experiences of curriculum interpretation and enactment. Some teachers asserted that technology education was still misrepresented in their local community because of a lack of knowledge and because of the way that the subject had evolved. The sub-themes included:

4.4.1.1 Attitudes

All teachers described differing attitudes about the nature of technology education, how they perceived the subject could benefit learners, and the way it was being taught in their schools. For example, Alice described how the focus in their school was to foster a future-focussed climate of learning, where,

> We want our students to be able to solve problems and make stuff, to … make a difference to them, to the community, to the world [to] present that to an authentic audience … That is powerful, rather than taking a pencil case home and mum and dad say, "That's nice".

4.4.1.2 Ideologies

Technology teachers are likely to align with or be mediated towards four main perspectives, which are knowledge-based, social in nature, learner-centred, or philosophically driven (Reinsfield & Williams, 2015; Schiro, 2008). Participants' ideologies were identified in relation to the nature of the subject and the action strategies that described their teaching. For example, Helen explained that her teaching was moderated by students' attitudes towards their learning, stating:

> Some [students] are just slack … you can give them so many opportunities to fill in little things, and it just never really happens really. It is disappointing.
>
> … They are really here, at the back of their minds, to cook … it's at the back of their minds all of the time. Like, "Okay, well let's just get this paperwork over, have a good chatter, and then we'll get back to our next practical".

4.4.1.3 Opinions and Valued Knowledge

The opinions expressed about the nature of technology education related to past curriculum implementation and what was subsequently valued. Colette acknowledged the influence of societal change, but still valued skills and knowledge of equipment use, stating:

> Knowledge, as we know, in this day and age, is moving at such a pace that you couldn't possibly keep track of all of it … and particularly in technology … and so, in some ways, ignorance is an asset as a teacher
>
> I do value skills and I must admit … I'm always amazed at [students'] lack of skills, particularly with woodworking. They move into woodworking, and they have very little hand tools skills and things like that to build on.

4.4.1.4 Objectives

Teachers' objectives for learning are likely to be affected by their perceptions about the nature of the subject, the social, cultural, political, and economic discourse in which they practice, as well as what is legitimate knowledge (Williamson, 2013).

The data indicated teachers' intentions to consolidate their understanding of the technology curriculum in their school, within their specialist area, and with a view to improve their classroom-based practice. Participants highlighted this could be done by affirming their current understandings, identifying some goals for their future practice, through the integration of curriculum knowledge, as well as through pedagogical risk-taking. For example, Colette described a professional tension between her personal goals and the need to be responsive to the community's expectation when teaching technology. She stated:

> We want the parents to be pleased with what comes home and so if the quality of work isn't there … therefore, do you get projects done of a high standard, based on whether the kid can cut a piece of material perfectly straight? I mean, of course, I love them to be able to cut everything straight and teach them all that …
>
> And so [if] ideas are way out there and innovative and they push the boundaries and that's worth something where your practical skills are subpar. Where this kid doesn't have an original thought in his head but can produce, you know, what you want them to produce … I think both of [these students] should be able to achieve and excel.

4.4.1.5 Pedagogical Risk-Taking

In a school where there are traditional perceptions of technology education within the community, teachers may feel that practice, which aligns with the curriculum, can be risky. For example, Helen stated:

> I spoke to Peter and I said, "What do you think about us putting a small unit into Year 10 and trying it out?" and he said, "I'd be happy to give it a go" and I thought, as a team we could help each other get it right the first time, we wouldn't have too much risk of failure.

Four teachers perceived a continued need to assure the position of the subject in the school curriculum. They felt that they were required to moderate the number of changes that they made to their practice because of their community's expectations about the learning that *should* occur when students were studying technology education. Alice stated that there were continuing tensions for technology teachers, indicating:

> The unsustainability of the secondary model perpetuates the content cramming philosophy. The process-orientated [approach] is really good and technology teachers are really good at teaching procedural knowledge … I mean, they've got that knowledge but it doesn't actually really help them. It's actually the social knowledge and the conceptual knowledge that changes the way that they think about the world. So that's our challenge really.

4.4.2 Phase Two: Curriculum Planning

Teachers' interpretation of the curriculum is represented in two sub-themes, comprising teachers' meaning-making processes and written discourse. All participants acknowledged the meaning-making processes that were required to interpret the curriculum to then apply their understandings in practice—for their specialist area of technology. Mike identified a need to gain support from digital technology colleagues in other schools and indicated:

> … we have had to shoehorn some of the things to make it fit technology [education] … Only because [of] the old way they teach it still, really.
>
> [Technology education is] very structured. ITs not structured; it's a very fluid industry. And it doesn't really have a structure because it is all about thinking outside the box. And if you output too much structure, you can't go outside the box.

Bernadette, Mike, and Graham used terminology in department meetings that suggested a familiarity with the intent and structure of the technology curriculum (MoE, 2007). Helen, Colette, and Alice predominately used terminology that related to the practical nature of the technology curriculum—and in connection to the development of technological outcomes.

4.4.3 *Phase Three: Teaching Methods*

There was a diversity of perspectives and attitudes represented by individual teachers, with disparity in espoused perceptions and practice. Alice and Graham represented the view that learning should focus on developing student capability and in response to students' interests. They presented the impression that their practice was contemporary in nature. During their lessons, however, these teachers' practice emphasised the outcomes being developed—with a view to exemplify meaning for students. Teachers' espoused perceptions and practices are presented in Table 4.2.

The findings indicated that Bernadette, Colette, and Helen were all relying on their habitual (existing & embedded) knowledge (Määttänen, 2015; Meyer & Land, 2003; Perkins, 1999). Alice, Bernadette, Graham, and Mike applied some of the technological concepts to differing learning contexts—with differing success. The ways that teachers engaged with, interpreted, and enacted the curriculum led to insight into the knowledge that they were finding troublesome. Figure 4.1 shows each participant's positioning, based on their understandings.

The next section describes how teachers' understandings of the curriculum were represented through their emerging troublesome knowledge and liminal (transitional thinking) space.

4.4.4 *Connecting Liminal Space and Troublesome Knowledge*

Troublesome knowledge is conceptualised here as understanding that is "alien, counter-intuitive, ritualized, inert, tacit or even intellectually absurd at face value"

Table 4.2 Teachers' espoused perceptions and practice

Participant	Espoused perceptions	Practice
Alice	Technology education can support learning about the nature of technology, in an integrated manner, and to focus on issues like sustainability, enterprise, and empowerment	Students need to develop skills and knowledge first, to be successful in technology education
Bernadette	Technology education can provide academic and vocational pathways for learning. To develop student capability, teachers need to expose learners to a range of different contexts	An explicit focus on teaching the technological concepts as they are presented in the curriculum
Colette	Technology education provides opportunities to allow students to direct their own learning and be innovative in their thinking	Practice was based upon the replication of a pre-determined outcome, and teacher-directed in nature
Graham	The practical nature of the subject is a "hook" for students, to engage them in their learning. He wanted learning to be "visible" and engaging for his learners	Practice focussed on the establishment of routines, rules of practice, and the making of a quality outcome
Helen	Helen expressed concerns about how food technology was perceived by the students in her school. She indicated that they only wanted to engage in practical tasks	Practice focussed on classroom management and emphasised the planning for and organisation during practical tasks
Mike	Digital technology does not always align easily with technology education. There are times where students have the skills to be self-regulating but sometimes, they must be told what they are making	Practice focussed on the Technological Practice strand of the curriculum. Students were designing a website based on a topic of their interest

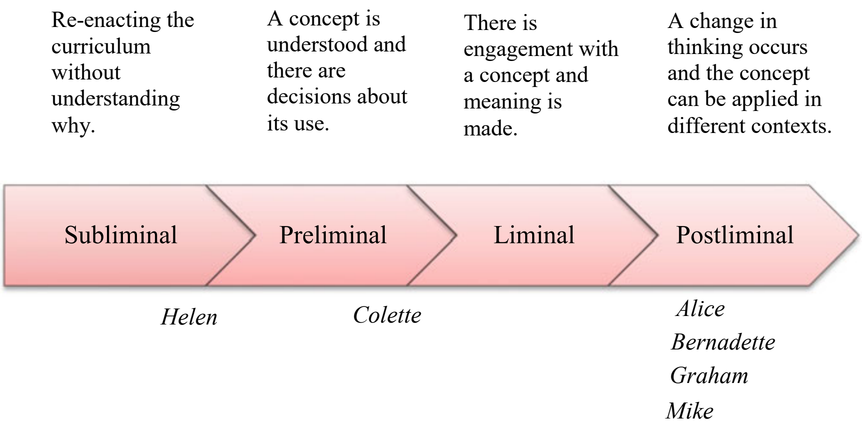

Fig. 4.1 The liminal space positioning for participants. Adapted from Meyer et al. (2008)

(Meyer & Land, 2003, p. 2). It can be difficult for teachers to articulate what they value, but this can manifest during a particular learning activity.

4.4.4.1 Alice

There was a tension between Alice's espoused (future-focussed) perceptions and the way that this was translated into practice. She explained that whilst she had a learning goal in mind (Stoll et al., 2012), she had found it difficult to manage a large and behaviourally challenging group of students who were working collaboratively on a class project. It was not Alice's understanding of the curriculum concepts limiting her practice but instead her inability to support the needs of her learners in a newly conceived learning context (Zuga, 1989).

4.4.4.2 Bernadette

Bernadette had a national reputation for her work with the technology curriculum and is positioned at the post-liminal stage of understanding in Fig. 4.1. She acknowledged, however, that because of her leadership role, her practice remained inert and ritual in nature, because she had to prioritise her colleagues' evolving understanding of the curriculum. This is where the knowledge she found troublesome emerged. During one department meeting, Bernadette provided food-specific examples for Helen, whom she knew was experiencing difficulty when interpreting the curriculum, for her own specialist area. The examples Bernadette provided appeared confusing to Helen. There is the risk in such circumstances, misleading examples can be volunteered, which further confuse practitioners who are already experiencing difficulty making meaning of the technology concepts.

4.4.4.3 Colette

Colette recognised that her knowledge of the New Zealand curriculum (MoE, 2007) was evolving because she had been in the country for only a brief time. She argued that rather than her enactment being constrained by her own understanding of the curriculum, however, it was the school's discourse limiting her practice because it was reflective of elitist perspectives about the role of technology and the suitability of students for distinct roles in society (Hill, 2003; McLintoch, 1966; Reid, 2000; Williams, 2013). Such an approach would counter the view that technology education should be an entitlement for all students, irrespective of their ability and skill (Ferguson, 2010; Kimbell & Stables, 2007).

Colette's understanding of the technology curriculum was at a pre-liminal stage. She described difficulty when engaging with some of the curriculum support material, to interpret the concepts for her own specialist area of materials technology.

It appeared that the knowledge she needed to make meaning of the technology curriculum was alien to her (Meyer & Land, 2003; Perkins, 1999).

4.4.4.4 Graham

There was no evidence to suggest that Graham was experiencing troublesome knowledge or that he needed to transition any liminal space in relation to his understanding of the curriculum concepts. He recognised a need to accommodate all aspects of the technology curriculum, whilst being responsive to students' interests. Graham's data indicated, however, that his practice was being limited by the organisational structures within the school. His enactment of technology education was being impacted by the expectation that he was responsive to student needs, within an integrated curriculum, and under pressured timeframes. Graham understood the curriculum concepts and how they could be applied in practice but because of the constraints placed on his practice, he reverted to ritual knowledge (Meyer & Land, 2003; Perkins, 1999), which focussed on the replication of pre-existing outcomes.

4.4.4.5 Helen

Helen found the curriculum concepts both conceptually difficult and alien (Meyer & Land, 2003; Perkins, 1999) and was using Bernadette's resources to support her teaching. Helen's instructions emphasised expectations around behaviour and a technical approach to learning. Troublesome for Helen was the notion that students' practice should *not solely* be derived from the production of outcomes to develop the necessary skills for the transition to the senior secondary Hospitality programme. She gave the impression (during department meetings) that she was engaging with the curriculum, yet she was replicating others' ideas and continuing to practice in a manner that reflected historically placed practices (Paechter, 1995).

4.4.4.6 Mike

What Mike found troublesome was not the interpretation of the curriculum or indeed its enactment but how he *managed* this process to track students' coverage of the technological concepts. He indicated that whilst he felt confident that he was meeting the curriculum requirements, there was not always the evidence to substantiate this. Mike asserted that he might not explicitly cover curriculum concepts within this delivery but felt that students would intuitively develop their understandings of technology because of the projects with which they engaged. Mike's coverage of the curriculum was based upon a process-driven perspective, which relied on his ritual and inert knowledge (Meyer & Land, 2003; Perkins, 1999). He consistently sought new ideas to enable engaging learning contexts. What he found troublesome was how to make explicit links between his curriculum knowledge, planning for learning, and practice.

Each teacher's understanding was connected to their experience of teaching technology, their engagement with the curriculum, and the school-based circumstances that were mediating their practice. The findings suggested that there were pervasive and historically based assumptions about the nature of technology education in both schools. Fortunately, the data also indicated that if technology teachers were motivated to challenge others' thinking, engage in dialogue about the subject and how it is enacted in the classroom, and support the community's developing understandings, these assumptions could be reconceived. The suggested strategies to enable technology teachers' practice are discussed in the next section.

4.5 How This Knowledge Might Be Used to Improve Teaching and Learning

The findings outlined in the previous section imply that threshold concepts can support changes in technology teachers' thinking and practice. However, teachers' professional learning can depend upon the discernment of an individual's understanding—in this case, of the technological curriculum concepts, which can lead to a new comprehension or teaching strategy for practice (Marton, 2007). When the concepts that define the technology curriculum (MoE, 2007) are troublesome for teachers, they will likely experience difficulty interpreting and making meaning of generic ideas, for their own specialist area, and for enactment in the classroom. Such troublesome knowledge derives the question, "*How can teachers' make meaning of a curriculum to develop their knowledge for practice?*" and allows a focus on new ways of thinking in three stages. These stages are identified in Fig. 4.2.

The ideas in this chapter challenge the assumption that specialist teachers of technology are intuitively able to make the liminal connections between their specialist understandings and the generic concepts in the curriculum. Instead, specialist knowledge (of woodwork, for example) can be distinct to an ability to interpret the technological concepts in the curriculum, for application in a teacher's practice. This is pertinent because it means that a more explicit focus on interpreting the curriculum concepts, for application within a technological area (rather than the other

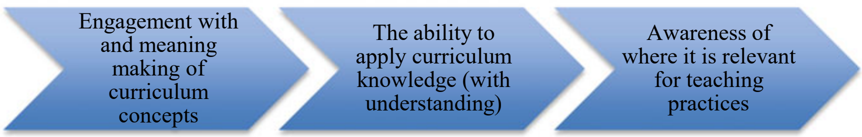

Fig. 4.2 Navigating troublesome curriculum knowledge

way around), can provide a strategy for supporting teachers' evolving curriculum understandings.

The apparent disconnect between curriculum theory and practice is represented through teachers' perceptions of the nature of technology education, and the way they enact the curriculum in practice, to enable student's learning. To enable a sustained change in practice, teachers are likely to be required to reflect upon their perceptions of the purpose of technology, then explicitly make meaning explicitly of explicitly and teach the technological curriculum concepts. This presents a tension for teachers who prioritise their specialist knowledge over the curriculum knowledge required for students to learn about technology education.

It is evident that for teachers (like Helen) to make meaning of the curriculum there needs to be access to professional learning outside of their immediate context, with a view to situate and find connections with the theoretical concepts that define its current nature (Reinsfield, 2016a, b, 2018; Williams, 2013). Whilst such opportunities are available for teachers in New Zealand, there appears a preference for generic professional learning models, which promote workshop-style, disseminated information. Sustained and personalised professional learning requires teachers to critically engage with and develop their practices. Such activities can either unite or destabilise teacher understandings and cause further tension for some practitioners (Mortimer & Scott, 2003). The following teaching approaches present strategies for consideration, with a view to challenge outdated representations of technology education.

4.5.1 Changing Teachers' Perceptions

To change technology teachers' attitudes and subsequent teaching practices to align with a learner-centred approach, there needs to first be an appreciation that students are more likely to engage in their learning if opportunities are focussed on their interests or if they are involved in the decision-making processes about their learning. One strategy to accommodate such an approach would be for teachers to *reflect upon a project* context that has been recently used with students, to consider how it could become more open-ended, and/or to *seek feedback* from them about how it might encourage increased student engagement and/or autonomy. An openness to professional reflection and an understanding of how such learning introduces learners to technological concepts within the curriculum, at an appropriate level, is necessary to enable this process. It is acknowledged here, however, that there are several factors that can moderate the effectiveness of such an approach. Figure 4.3 identifies how teachers' perceptions can influence their practice in technology education and proposes some transitions in thinking to curriculum interpretation, implementation, and enactment.

Figure 4.3 identifies how technology teachers' perceptions can be represented to reflect curriculum understanding, through its interpretation, implementation, and enactment. Whilst there are times when it is appropriate for students to replicate

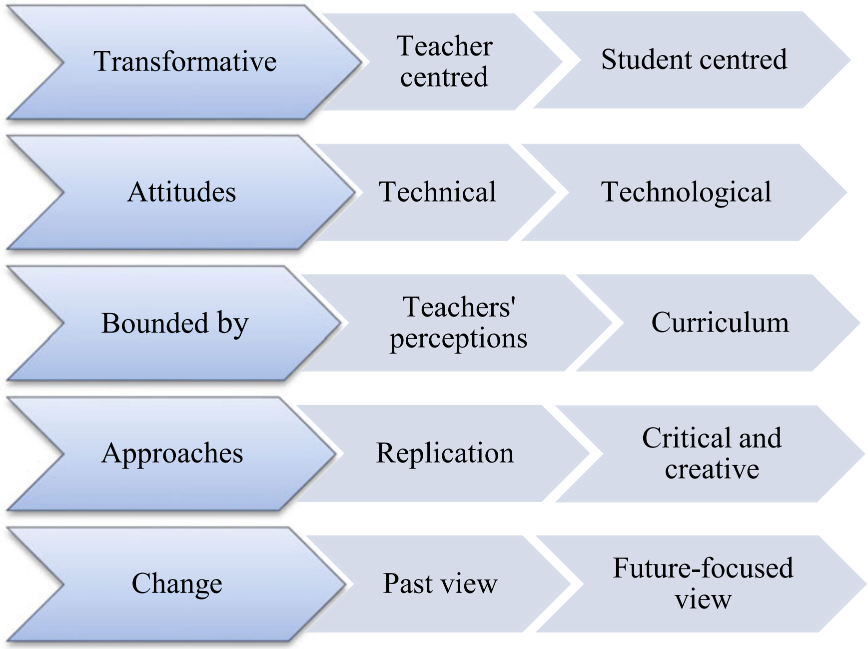

Fig. 4.3 Perceptions and practice in technology education

products, learner-centred approaches can provide an alternative to fully engage and extend students' understanding of future-focussed issues in technology education. Learner-centred teaching approaches can be enacted in differing ways and using strategies that negotiate the context of the learning with students, or with teaching approaches that advocate for the development of student autonomy (e.g., inquiry-based). In such cases, the learning context could be inspired by global or local needs to generate ideas and diverse ways to conceptualise technological issues. For example, the following design context presents an opportunity for learners to consider pertinent societal issues:

Climate change has led to an increasing number of droughts in New Zealand. Associated with these droughts are bush fires, which can have significant implications for properties, people, and surrounding wild life.

For those living in parts of New Zealand where bush fires are prevalent, dry grasses and any thick undergrowth is kept away from the home. In cases of emergency, people have to leave their home, their livestock and animals and there is often uncertainty about what has become of them.

Design a technological solution that might monitor, protect, or mitigate risk for livestock or animals during a local emergency.

To facilitate this type of approach to learning in technology, teachers may need to re-position their perceptions of the subject to foster innovative thinking, rather than to solely develop practical skills.

4.5.2 Teaching Approaches

Instead of focussing on the teaching of curriculum, technology teachers in secondary schools can emphasise rules, project planning, and classroom management (Reinsfield, 2020). When students become disengaged in technology education, teachers can retreat to practices that focus on the replication of high-quality practical outcomes. This strategy can also be used to counter underachievement. By doing so, such practices (unintentionally) perpetuate a technical approach to technology education. Figure 4.4 suggests strategies to enable a change in teachers' thinking and practice.

The following section proposes ways to support technology teachers' transition to a new conceptual space (Meyer & Land, 2006), and promotes the enactment of the technology curriculum, *in practice*. Technological approaches (Reinsfield & Williams, 2015) to the subject can be enabled when teachers:

- engage in *dialogue* with their students to negotiate learning outcomes
- have a very clear *learning goal*
- have a *holistic understanding* of technology education, which can then be adapted to align with the *school* context and developed to be *responsive* to

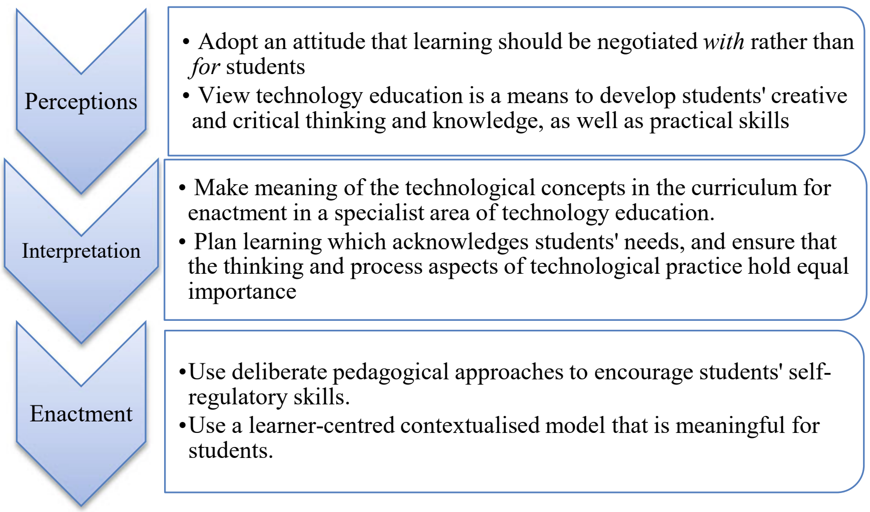

Fig. 4.4 Strategies to address technology teachers' enactment of the curriculum

students' emerging academic and social needs (Carrington & Robinson, 2006; Kanjanabootra & Corbitt, 2016; Korthagen et al., 2001; Loughran & Berry, 2005).

Where teachers default to traditional approaches for the teaching of technological concepts, pedagogy is not easily connected with the values represented in the curriculum (MoE, 2007). Further, such approaches can position the subject as being primarily about the transmission of teachers' knowledge, rather than to explore and respond to students' interests.

A learner-centred approach requires teachers to be responsive to, and facilitative of, the development of knowledge and skills *as they emerge* in the classroom. Practical work is a valuable means to engage students in their learning in technology education and can also be enacted through experimentation, prototyping, and testing, not just through the replication or adaptation of existing products. Whilst practical skills and knowledge in technology education classes are often taught according to the teachers' plan for the learning, they can also be taught "Just in Time" and in response to a student's progress (Novak, 2011; Osmond & Goodnough, 2011). Such an approach provides learners with increased autonomy and enables them to learn about technology education in an iterative manner—according to their interests. To effectively manage such an approach to learning, teachers need to be adaptive to the direction that students choose to take in their technological development. In such circumstances, teachers can support students to:

- *explore* their own learning context from a problem-solving perspective, and to address a need or opportunity.
- *identify* what they need to know and develop understanding at a time that makes sense to them.
- *construct knowledge* collaboratively or individually to facilitate a successful concept or outcome.

Barriers to teachers' professional learning can be impacted by their perceptions, understandings of the curriculum concepts, school structures, and community expectations. This implies opportunities for further research to explore how school-based, collaborative efforts can be strengthened to foster a climate where teachers are expected to engage with the technology curriculum for its enactment in a progressive, future-focussed, and learning-centred context. To enable this, however, school structures must be supportive and empowering of teachers' evolving practice.

4.6 Conclusion

This chapter reports on research, which explored six secondary teachers' perceptions and practice in technology education in New Zealand, from a perspective where the curriculum is viewed to expose students to future-focussed learning. New knowledge emerged about the nature of technology education, confirming a disparity between some teachers' perceptions and the way that this translated into their emerging practice. Recommendations have been made to promote strategies that teachers can use to navigate potential thresholds of understanding or troublesome knowledge and motivate a review of approaches to think about curriculum interpretation and enactment, and with a view to facilitate a transformation practice in technology education.

References

Adler, M. J. (1982). *The paidea proposal: An educational manifesto*. Collier Macmillan.

Carrington, S., & Robinson, R. (2006). Inclusive school community: Why is it so complex? *International Journal of Inclusive Education*, *10*(4–5), 323–334. https://doi.org/10.1080/13603110500256137

Dakers, J. (2006). *Defining technological literacy: Towards an epistemological framework*. Palgrave MacMillan.

Ferguson, D. (2010). *Development of technology education in New Zealand schools, 1985–2008.* Ministry of Education.

Fox-Turnbull, W., & O'Sullivan, G. (2013). Supporting conceptual understandings of and pedagogical practice in technology through a website in New Zealand. *International Journal of Technology and Design Education, 23*(2), 391–408. https://doi.org/10.1007/s10798-011-9185-1

Hill, A. M. (2003). An analysis of the debate: Has the study of technology a vocational or academic purpose. In *Proceedings of the Pupils attitudes toward technology: Thirteenth international conference on design and technology* (pp. 87–92). Glasgow.

Hoyle, E. (2008). Changing conceptions of teaching as a profession: Personal reflections. In D. Johnson & R. Maclean (Eds.), *Teaching: Professionalization, development and leadership* (pp. 285–304). Springer.

Jones, A. (2009). Towards an articulation of students making progress in learning technological concepts and processes. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 407–417). Sense.

Jones, A., & Carr, M. (1992). Teachers' perceptions of technology education: Implications for curriculum innovation. *Research in Science Education, 22*(1), 230–239. https://doi.org/10.1007/BF02356900

Jones, A., & Compton, V. (2009). Reviewing the field of technology education in New Zealand. In A. Jones & M. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 93–104). Sense.

Jones, A., Harlow, A., & Cowie, B. (2004). New Zealand teachers' experiences in implementing the technology curriculum. *International Journal of Technology and Design Education, 14*(2), 101–119. https://doi.org/10.1023/B:ITDE.0000026549.08795.9e

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. https://doi.org/10.1007/s10798-011-9174-4

Kadi-Hanifi, K., & Keenan, J. (2016). Finding the "a-ha" moment: An exploration into higher education in further education teacher self-concept. *Research in Post-Compulsory Education, 21*(1), 73–85. https://doi.org/10.1080/13596748.2015.1125672

Kanjanabootra, S., & Corbitt, B. (2016). Reproducing knowledge in construction expertise: A reflexive theory, critical approach. *Construction Management and Economics, 34*(7–8), 561–577. https://doi.org/10.1080/01446193.2016.1151064

Kimbell, R., & Stables, K. (2007). *Researching design learning: Issues and findings from two decades of research and development*. Springer.

Korthagen, F. A., Kessels, J., Koster, B., Lagerwerf, B., & Wubbels, T. (2001). *Linking practice and theory: The pedagogy of realistic teacher education.* Routledge.

Loughran, J., & Berry, A. (2005). Modelling by teacher educators. *Teaching and Teacher Education, 21*(2), 193–203. https://doi.org/10.1016/j.tate.2004.12.005

Määttänen, P. (2015). *Mind in action: Experience and embodied cognition in pragmatism.* Springer.

MacGregor, D. (2017). Exploring the role of professional learning communities in supporting the identify transition of beginning design and technology teachers. In J. Williams & D. Barlex (Eds.), *Contemporary research in technology education* (pp. 143–159). Springer.

Mansell, H. L., Harold, B. D., Hawksworth, L. J., & Thrupp, M. P. (2001). The perceived impact of the technology curriculum. *Set, 1*, 23–28.

Marton, F. (2007). Towards a pedagogical theory of learning. In N. J. Entwistle (Ed.), *Student learning and university teaching* (pp. 19–30). British Psychological Society.

McLintoch, A. H. (Ed.). (1966). *Education, post-primary. Te Ara: The encyclopaedia of New Zealand.* http://www.TeAra.govt.nz/1966/E/EducationPost-primary/en

Meyer, J. H., Land, R., & Davies, P. (2008). *Threshold concepts and troublesome knowledge: Issues of variation and variability.* Sense.

Meyer, J. H. F., & Land, R. (2003). Threshold concepts and troublesome knowledge: Linkages to ways of thinking and practicing. In C. Rust (Ed.), *Improving student learning: Theory and practice ten years on* (pp. 412–424). Oxford Centre for Staff and Learning Development.

Meyer, J. H. F., & Land, R. (2005). Threshold concepts and troublesome knowledge: Epistemological considerations and a conceptual framework for teaching and learning. *Higher Education, 49*(3), 373–388. https://doi.org/10.1007/s10734-004-6779-5

Meyer, J. H. F., & Land, R. (2006). Threshold concepts and troublesome knowledge: Issues of liminality. In J. H. F. Meyer & R. Land (Eds.), *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge* (pp. 19–32). Routledge.

Ministry of Education. (2007). *The New Zealand curriculum.* Learning Media.

Ministry of Education. (2014). *Four-year plan and statement of intent*, *2014–2018.* https://education.govt.nz/ministry-of-education/publications/four-year-plan-and-statements-of-intent/

Ministry of Education. (2017). *Digital technologies: Hangarau Matihiki.* https://education.govt.nz/assets/Documents/Ministry/consultations/DT-consultation/DTCP1701-Digital-Technologies-Hangarau-Matihiko-ENG.pdf

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms.* McGraw-Hill Education.

Novak, G. M. (2011). Just-in-time teaching. *New Directions for Teaching and Learning, 128*, 63–73. https://doi.org/10.1002/tl.469

Osmond, P., & Goodnough, K. (2011). Adopting just-in-time teaching in the context of an elementary science education methodology course. *Studying Teacher Education*, *7*(1), 77–91. https://www.learntechlib.org/p/52280/

Pacey, A. (1992). *The maze of ingenuity: Ideas and idealism in the development of technology*. MIT.

Paechter, C. (1995). Sub-cultural retreat: Negotiating the design and technology curriculum. *British Educational Research Journal, 21*(1), 75–87. http://www.jstor.org.ezproxy.waikato.ac.nz/stable/1501284.

Perkins, D. (1999). The many faces of constructivism. *Educational Leadership, 57*(3), 6–11.

Reid, M., (2000). Towards effective technology education in New Zealand. *Journal of Technology Education, 11*(2), 33–47. https://doi.org/10.21061/jte.v11i2.a.3

Reinsfield, E. (2020). Time to re-conceptualise the role of secondary schools in New Zealand: Looking ahead to the future in technology education. *International Journal of Adult Vocational Education and Technology.* https://doi.org/10.4018/IJAVET.2020040104

Reinsfield, E., & Williams, J. (2015). Exploring teachers' enactment of the technology curriculum. In *Technology education New Zealand conference, Hamilton New Zealand.* Retrieved from http://tenzcon.org/2015-conference/2015-conference-papers

Reinsfield, E. (2012). *Drivers for change in technology education in New Zealand.* [Unpublished master's directed study]. University of Waikato, New Zealand.

Reinsfield, E. (2014). Secondary school technology education in New Zealand: Does it do what it says on the box? *Teachers and Curriculum, 14*(1), 45–51. https://doi.org/10.15663/tandc.v14i1.94

Reinsfield, E. (2016a). A future focus for teaching and learning: Technology education in two New Zealand Schools. *Teachers and Curriculum, 16,* 67–76. https://doi.org/10.15663/tandc.v16i1.122

Reinsfield, E. (2016b). Technology education in the New Zealand context: Disparate approaches to meaning making of the curriculum and the implications for teachers' evolving knowledge for practice. *Australasian Journal of Technology Education, 3*, 1–18. https://doi.org/10.15663/ajte.v3i1.39

Reinsfield, E. (2018). Secondary technology teachers' perceptions and practice: Digital technology and a future-focused curriculum in New Zealand. *Waikato Journal of Education, 23*(2), 61–74. https://doi.org/10.15663/wje.v23i2.581

Schiro, M. S. (2008). *Introduction to curriculum ideologies. Curriculum theory: Conflicting visions and enduring concerns.* Sage.

Stoll, L., Harris, A., & Handscomb, G. (2012). *Great professional development which leads to great pedagogy: Nine claims from research.* National College for School Leadership. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335707/Great-professional-development-which-leads-to-great-pedagogy-nine-claims-from-research.pdf

Tyack, D. B. (1988). Ways of seeing: An essay on the history of compulsory schooling. *American Educational Research Association. 46*(3), 24–58. https://doi.org/10.17763/haer.46.3.v73405527200106v

de Vries, M., & Mottier, I. (2006). *International handbook of technology education: Reviewing the past twenty years*. Sense.

de Vries, M. (2005). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers.* Springer.

Williams, P. J. (2009). Technological literacy: A multiliteracies approach for democracy. *International Journal of Technology and Design Education, 19*(3), 237–254. https://doi.org/10.1007/s10798-007-9046-0

Williams, P. J. (2013). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education, 23*(1), 1–9. https://doi.org/10.1007/s10798-011-9170-8

Williams, P. J., Jones, A., & Buntting, C. (2015). *The future of technology education.* Springer.

Zuga, K. F. (1989). Relating technology education goals to curriculum planning. *Journal of Technology Education, 1*(1), 34–58. https://doi.org/10.21061/jte.v1i1.a.5

Elizabeth Reinsfield is Director of Undergraduate and Graduate Programmes and a Senior Lecturer in the Division of Education, at the University of Waikato, New Zealand. Her research includes a focus on teachers' and student teachers' readiness to engage with and enact the technology curriculum. In particular, she is interested in cross-generational perceptions of innovation, and the opportunity that technology education provides, to enhance future-focused thinking and responses to societal need.

Chapter 5
Rhetoric to Reality: Understanding Enacted Practice in Technology Education

Andrew Doyle

Abstract For some time, there has been a recognition that the intended goals for learning in technology education have failed to manifest in practice. This chapter reports on my thesis that investigated the alignment between the international rhetoric and day-to-day reality of technology education. As the intermediary between policy and practice, the technology educator was the focus of this investigation. As noted in the title, however, this work did not focus on practice, but rather *enacted practice*, that is, I sought to unpack teachers' motivations for teaching specific content in specific ways. The implications from the thesis are twofold. First, a framework of enacted practice, teacher knowledge, and beliefs is put forward. The framework acknowledges how subject matter knowledge is utilised in technology education in striving for more comprehensive ways of understanding practices. Secondly, in taking a preliminary step towards understanding enacted practices, teachers' purposes for teaching technology education are investigated. The chapter culminates by discussing the implications for technology education practitioners in articulating and teaching their subject.

Keywords Technology education · Pedagogical Content Knowledge (PCK) · Grounded theory · Conception of technology · Enacted practice

5.1 The Questions I Asked and Why They Are Important

I engaged with doctoral studies because of my experiences as a student in Initial Technology Teacher Education (ITTE). Throughout my four years as an undergraduate, I was introduced to the term 'technology education' for the first time – and I struggled greatly with trying to understand exactly what it was referring to. The

A. Doyle (✉)
KTH Royal Institute of Technology, Stockholm, Sweden
e-mail: andrewdoyle@exe-coll.ac.uk

Exeter College, Exeter, England

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_5

Irish national context influenced this consternation as there are four different subjects on the curriculum that are said to make up 'the technologies': Engineering, Wood Technology, Applied Technology, and Graphics, four subjects with quite different contexts of application. Broadly I was interested in the commonality between these subjects – by asking the question, what makes these subjects 'technology education'?

From engaging with the literature surrounding the nature of technology, it became clear that the contentions in articulating a specific purpose for 'technology education' was something that has prevailed for some time. This is shown by the multiple different philosophical (Dakers, 2014; Gibson, 2008; Ingerman & Collier-Reed, 2011; Kelly et al., 1987; Petrina, 2000) and empirical (Ritz, 2009; Rossouw et al., 2011) investigations of how to articulate goals for engaging with technology education. In the place of specific goals for engagement with the subject, broad conceptual terms have come to permeate the literature. Technological capability and technological literacy were dominant; however, technological perspective, technological competence, and technacy are all used to describe intended learning outcomes in the subject area. These higher constructs are often used to describe learning outcomes in a space where the specific subject matter is elusive. They are by their very nature, context-independent.

It should be noted here that the use of these broad conceptual terms within the literature is accepted, and it is not my intention to challenge them. However, from the perspective of a technology educator, my research began by asking what this means for teaching technology. The discourse of technology education research is littered with the challenges associated in shifting pedagogical paradigms (Dakers, 2005). There are theorised 'rhetoric–reality tensions' (Banks & Barlex, 1999; Kimbell, 2006; Spendlove, 2015) between the intended learning outcomes, and the reality of day-to-day teaching and learning. As the intermediary between rhetoric, as reflected in international discourse and national curricular specifications, and reality, as manifested in day-to-day practices, my thesis work centred on the technology educator. Specifically, my research focussed on the following questions:

1. How do technology teachers describe their enacted practices relative to the more general aims of technology education?
2. How can teachers' enactment of technology education be investigated?
3. How do technology teachers represent the purpose of teaching technology through reflection on their enacted practices?

5.2 How I Tried to Answer the Questions

To answer the stated research questions, two different approaches were taken. First, to explore the current state of research regarding how enacted practice in technology education is investigated and understood, a review of the literature was undertaken. This review resulted in the presentation of a framework that proposed an alternative way of thinking about Pedagogical Content Knowledge (PCK) research in the subject. As well as focussing on the literature surrounding enacted practice and the nature of technology education, I used interviews with technology teachers to better understand the nature of their practices, and their rationale for teaching technology.

5.2.1 Identifying Constructs and the Literature Review

In addressing the question 'how can teachers' enactment of technology education curricula be investigated?' my initial focus was in reviewing the literature surrounding the practices in teaching more generally. A prevalent theme that quickly emerged here was the construct of PCK. PCK was initially proposed by Shulman (1986) in the late 1980s as a way of articulating what it is that a teacher knows. Despite having been researched extensively in the science and mathematics education research communities, PCK in technology education has received little attention. Furthermore, several researchers had previously noted the potential utility of PCK research in technology education (de Vries, 2003; Jones et al., 2013; Mioduser, 2015). As a result of its potential utility in explaining the nature of teachers' enacted practices (Abell, 2008), I undertook an extensive literature review of PCK in general, and as this progressed I focussed on investigations in technology education and closely related fields.

5.2.2 Talking to Teachers

My research focussed on investigating the role of technology teachers, as a result of the findings from the literature review. As the main point of interest in terms of data was teachers' enacted practices, a decision that had to be made early on was whether it would be necessary to observe practices, or if teachers' reflections on practices would be sufficient. As the amount of time to engage with observing practices would limit the breadth of teachers which could be surveyed, and there was a finite amount of time in which I had to survey teachers, interviews were decided as an efficient approach. The interview guide was developed based on the theoretical framework which was published at this point (Fig. 5.1). As will be discussed in the next section, the beliefs component of the model was specifically identified to be of importance in understanding practice in technology education, as teachers were theorised to have more autonomy in decisions regarding what to teach and how. Constructivist Grounded Theory was the specific methodological approach adopted. This was chosen as it allowed me as a researcher to focus on specific points of interest as the study progressed, while maintaining a broader focus on understanding teachers' purposes for teaching the subject.

As enacted practice itself was not the focus of data collection, there were several steps taken to ensure that teachers' reported practices reflected the reality of their day-to-day teaching. Firstly, the interviews were designed around learning activities that the participants selected from their teaching. This was facilitated by the situated

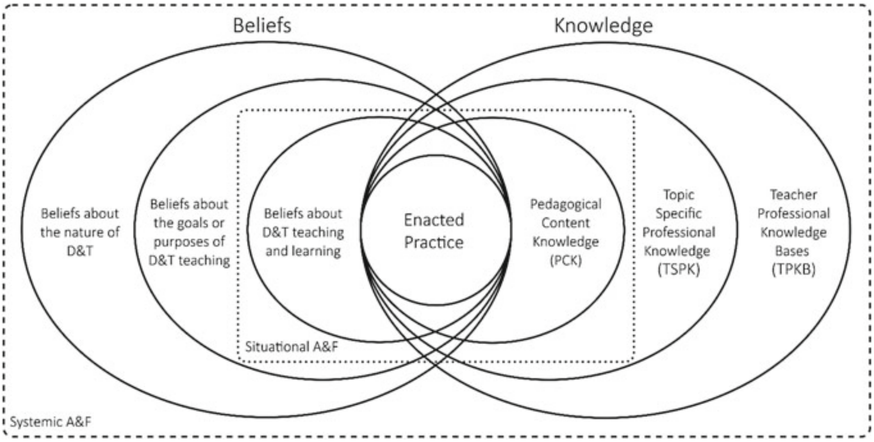

Fig. 5.1 Ecologically situated model of enacted practice, teacher beliefs, and knowledge (Doyle, Seery, Gumaelius, et al., 2019)

nature of the theoretical framework, in that although there were no direct observations of teaching, interviewees were required to reflect on their enacted practices throughout the data collection process.

5.3 What I Found Out

5.3.1 Rhetoric–Reality Tensions Prevail

The initial scoping study I undertook sought to investigate the theorised rhetoric–reality tensions in the context of Irish technology education. From this series of interviews, the tensions between international rhetoric and the reality of day-to-day practices appear to prevail. This was evidenced through the first significant theme identified in the analysis, a prominence of learning activities focussed on the development of technical knowledge and skills. This appears to be at tension with the broader goals for technological capability identified in technology curriculum and steering documents (NCCA, 2004). The more reductive approach towards engaging with technology education in these instances was characterised through minimal engagement with design, or in some cases, the truncation of curriculum content altogether. Central to these tensions appeared the nature of summative assessment, as participants highlighted the high stakes nature of preparation for such an assessment and detailed the resultant effects on their practices. The influences that summative examinations have on practice in Irish education have been well documented (MacAogáin, 2005). Unsurprisingly, one of the most often cited points of causation is the high-stakes nature of secondary education assessment, as results govern matriculation into tertiary education (Hyland, 2011). Similar findings were identified in my first study (Doyle, Seery, Canty, et al., 2019), where interviewees cited their schools as 'high achieving' and detailed the resulting cultural expectations placed upon them, ultimately facilitating teaching towards the exam epistemology.

Another significant point that emerged from this study was teachers' awareness of potential disparities between their personal construct of capability, and their decision about what to teach in the classroom. This resulted in teachers adopting pedagogical approaches which misaligned with their aspirations for teaching technology. Termed 'professional views on capability' this theme was founded on teachers questioning the nature of the current assessment systems, but also the nature of prevailing curriculum. An example of this was found where teachers discussed how they organised teaching and learning over a two-year programme of study:

> … in my head, right I have so much to get done, we do this today, we do this tomorrow. I know it's not ideal but you are facing the exam at the end, and you have to have the topics covered …

This brief example was of particular interest as it outlines the teachers' contention between what they do from day-to-day and their *ideal*. This contention, further evidenced by teachers' questioning of the nature of curriculum and assessment (Doyle, Seery, Canty, et al., 2019) pointed towards the need for a more nuanced understanding of the association between rhetoric and reality. Further, in considering the role of the technology educator and their motivation for teaching technology, the emphasis of this work changed to specifically examine enacted practice. The term *enacted* here sought to outline my intent to include teachers' motivations for practices in teaching technology. This point, and the difficulties associated with managing the different factors which influence teachers' decisions surrounding what to teach and how to teach it, influenced the direction of this thesis work which resulted in a focus on the technology educator as mediator of enacted practices.

5.3.2 Treatment of Knowledge and Implications for Investigating Technology Education Practices

With the evidence from the initial study identifying that there were tensions between individual teachers' conception of what was of importance to student learning, and the reality of their practices, attention was turned towards ways of explaining the nature of *enacted practice*. The approach taken was to consider the application of PCK as an educational construct and examine its utility in explaining enacted practices in technology education.

The previously noted difficulties associated with prescribing content for technology education emerged as a significant theme in this analysis. As authentic technological activity is said to be predicated on the application of 'provisional knowledge' (Kimbell, 2011) where multiple approaches to solving problems is encouraged, the application of contemporary perspectives on PCK was theorised to be premature.

The main reason for this was that PCK is predicated on the idea of how to present specific content for student learning (Shulman, 1986). However as noted, there is an apparent hesitancy in prescribing content for technology education, where goals for learning are instead presented through broad conceptual terms. Previous investigations of PCK in technology education suggested that the role of the teacher is amplified through the fluid treatment of content knowledge (Williams et al., 2012).

As an alternative to investigate PCK, therefore, a model was put forward that foregrounds the role that teachers' beliefs play in influencing decisions about what to teach and how (Fig. 5.1). PCK along with the other forms of teacher knowledge proposed in the Consensus Model of PCK (Gess-Newsome, 2015) were used in their capacity to explain enacted practice, as opposed to being the object of study in and of themselves. In other words, Fig. 5.1 is put forward as a model of enacted practice which includes PCK, and thus not intended as a model of PCK in technology education. For this reason, the framework was entitled the *ecologically situated model of enacted practice*.

In a pragmatic shift from a descriptive approach in conceptualising PCK to a model which has the potential to be more explanative of enacted practices, the model in turn situates enacted practice as the focal point. Building upon the 'amplifiers and filters' component of the Consensus Model of PCK (Gess-Newsome, 2015), the ecologically situated model distinguishes between situational and systemic amplifiers and filters of practice. Situational amplifiers and filters are everyday factors such as availability of resources or student demographics. On the other hand, systemic amplifiers and filters are viewed as factors which affect practices more broadly in the enactment of a subject. For example, the examination system as identified in my first study (Doyle, Seery, Canty, et al., 2019) would be considered a systemic filter of practice. With the model it is important to emphasise that teachers' beliefs will influence enacted practice in any subject, however in technology, as a result of the additional negotiation and justification regarding what to teach (Williams et al., 2016), it was theorised that teachers' beliefs may play a more significant role, and thus, should receive specific attention.

5.3.3 Multiple Conceptions of Why We Teach Technology

Following the presentation of the ecologically situated model, specific attention was given to the beliefs components that were proposed. The decision to focus on teachers' beliefs was influenced by the previous finding of a contention between teachers' personal conception of capability and their reported practices, as this finding suggested the importance of understanding teachers' intentions for teaching technology. The approach to analysis previously described resulted in the development of a grounded theory which consisted of three different conceptions of the purposes of teaching technology. These are presented in Fig. 5.2.

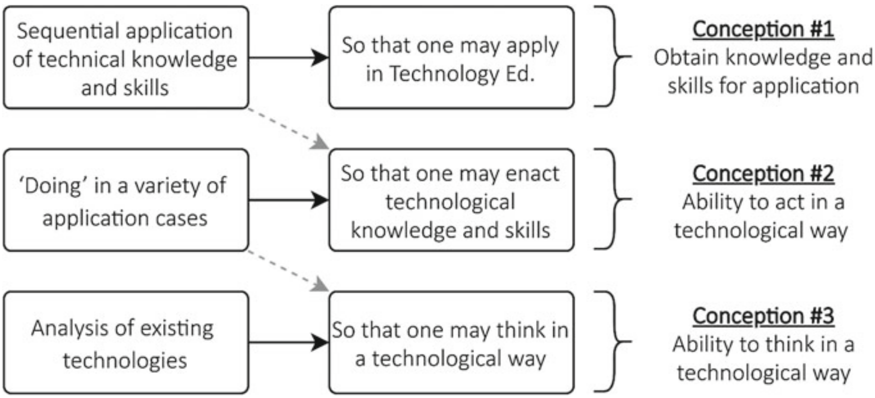

Fig. 5.2 Grounded theory of the purposes of teaching technology

The first conception resulting from the analysis situates the obtainment of knowledge and skills for application as the goal of the subject. Termed 'obtain knowledge and skills for application,' this conception was organised sequentially within a singular application case for technology. Application case here refers to the technical context in which technology education was taught, for example, in the Irish national context the subject 'Wood Technology.' The technical knowledge and skills associated with the application case were viewed as foundational to progression. It is here that an important distinction is drawn. Although a progression between conceptions was observed in some instances, for example, where the technical knowledge and skills were viewed as a prerequisite to acting in a technological way (Conception #2), some participants held that the obtaining of technical knowledge and skills remained the primary focus of teaching and learning throughout technology education.

With the previous conception, technical knowledge and skill development were held as the purposes of teaching technology; these are also held by interviewees as an appropriate way of framing technology education for another purpose, the 'ability to act in a technological way.' Here, students developed relevant technical knowledge and skills so that they may apply this knowledge in future tasks. In an alternative approach observed within this conception, interviewees situated the act of 'doing' technology in a variety of application cases as both the goal and organisation for teaching and learning throughout secondary education. With this approach, variability of application case was an intent of the teacher as the remaining commonality, the ability to negotiate novel problem situations, was identified as the key learning objective.

The third conception identified in this analysis foregrounded students' ability to critically think about various technologies, without necessitating engagement with a physical action. Termed 'ability to think in a technological way,' this conception is founded on teachers' assertions of 'technological thinking' and 'technological mind-set' as the ultimate goals of learning in the subject. Rationalised through an evolving technological world, with an exponential rise in the technologies around us, and our dependence upon such technologies, this conception outlines the importance of being able to 'critically engage with new technological innovations.' Two approaches to organise teaching and learning were observed within this conception. The first approach adopted the variability of application case approach, whereby students act in a technological way in a number of different cases, but the emphasis is placed on the ability to think in a technological way. The second approach negated the need to act in any instance, instead focussing student activity on deconstructing existing technological artefacts or systems analytically. Students here were encouraged to apply a series of 'theoretical lenses' through which to analyse the various technologies under consideration. An apparently sporadic selection of technologies for consideration was noted here. With either approach, the purpose behind engagement with technology education was removed from a specific application case. The purpose instead resided in students developing a broad understanding of 'what technology is and how it affects their lives' and ultimately, the 'ability to think in a technological way.'

5.4 How this Might be Used to Improve Teaching and Learning

This thesis makes a significant contribution to technology education as it applies to researchers, teacher educators, and policymakers. Furthermore, the implications of this research, as it is grounded in the reality of teachers' experiences, serve as a direct point of reference for teachers in the classroom. By association, the ultimate implication for this research in developing understandings of rhetoric–reality tensions lies in the enhancement of student learning. Framing a school subject through the ways in which knowledge is treated, rather than outlining specific knowledge for attainment, affords significant autonomy to the technology teacher in planning for and enacting their subject (Atkinson, 2017; Spendlove, 2012). The identified contentions between teacher's personal construct of capability and their reported enacted practices (Doyle, Seery, Canty, et al., 2019) suggest that the role of the technology teacher needs to be better understood. Although the conceptions identified in this thesis (Fig. 5.2) serve as a useful point of departure for considering the purpose of teaching technology that goes beyond the previously discussed higher constructs or representations of activity, the technology teacher must still make decisions about how to enact the subject.

As a result, the direct applications to teaching and learning made within this thesis are twofold. Firstly, from the perspective of better understanding enacted practice, the methodological framework presented in Fig. 5.1 and the reconceptualised perspective on PCK offers teachers, teacher educators, and researchers a mechanism through which to analyse and articulate enacted practice. Secondly, the grounded theory developed serves as a soundboard through which teachers, teacher educators, and researchers may reason about the different perspectives on how teachers conceive the purpose of teaching their subject.

5.4.1 Implications for Understanding Enacted Practice

The ecologically situated model was designed so that the idiosyncratic nature of activity in technology education (Stables, 1997) was placed as the focal point of investigation. In essence, the model affords a perspective on enacted practice whereby teacher knowledge and teacher beliefs may be used to explain enacted practice, however, they are not the focus of investigation. Although this perspective raises questions as to traditional approaches to investigating PCK as an entity (i.e. something which is measured), the rejection of this approach is becoming increasingly common in other subject areas (Chan & Hume, 2019). Furthermore, meso-level subject-defined or region defined investigation of the concept of amplifiers and filters affords a distinction between factors which are unique to an individual teacher, those that are imposed within a specific teaching episode (situational amplifiers and filters), or within an educational system more broadly (systemic amplifiers and filters).

The distinction between these situational and systemic amplifiers and filters is of importance to consider in how enacted practice is studied. Situational amplifiers and filters would be a concern for teachers and school leaders. Stemming from Kennedy's (2010) identification of widespread attributional error in the education research community, situational amplifiers and filters are everyday factors that affect teaching and learning. As such, they are essentially of concern in the management of the teaching environment and resources. Empirical evidence of the variety and impact of these factors would contribute to understanding the rhetoric–reality relationship in technology education. In particular, the role that the individual teacher, or the role that the teaching context, has in influencing enacted practice. In contrast, and more pertinently, a misalignment between beliefs and enacted practices may be due to a systemic level impediment to the actualisation of curricular objectives. The identification of systemic amplifiers or filters of enacted practice is more pertinent, given the widely accepted difficulties in shifting pedagogical paradigms in technology education (Dakers, 2005). The identification of factors of this nature would highlight issues beyond the remit of individual teachers, instead concerning policymakers and school and district authorities. Predicated on the identified misalignment between teachers' pedagogical aspirations and reflections on enacted practices, the identification of these factors at a situational or systemic level is of importance to realigning rhetoric and reality. Factors identified by these means may be used in the development of interventions which facilitate the (re)alignment of practices with policy.

Secondly, in taking the macro-level grounded theory approach, the three beliefs components of the proposed model were used to frame an investigation into the role that teachers' beliefs play in influencing enacted practices. The study resulted in a refining of the theorised relationships presented in the ecologically situated model, through the distinction between goals for activities in technology and purposes of teaching the subject. This was facilitated through the identification of the theoretical lenses used in formulating the conceptions in the grounded theory study, 'subject matter knowledge in technology education' and 'role of application case in technology education.' The interplay between technological activity and technological knowledge has consistently remerged throughout technology education research as a distinguishing feature of the subject area. During the grounded theory study, a conceptual jump was made to move beyond representations of activity, and questions were formulated to specifically address the subject matter knowledge in technology education. In what may appear abnormal to people unfamiliar with technology education, teachers exhibited significant difficulty in articulating the subject matter of technology in a more specific way than the nature of activity learners were to engage with. The lack of clarity here, as evidenced by the three conceptions identified only serves to further perpetuate rhetoric–reality tensions in technology education. Ultimately, this highlights the need to move beyond depictions of activity and conceptually oriented goals for learning (higher constructs) towards a more coherent theory of practice. In moving towards this theory, clarity surrounding what constitutes subject matter in technology education, and thus what constitutes technology education as a school subject is of importance to consider. The abstract ways in which the content of technology education was explain by teachers is shown in the below excerpt:

> **Interviewee:** I don't really know ... so that's ... oh, I'm trying to think of the context that you've put content in because... Because... Content. What were we using ... I guess the way I would look at it is that making [pause] thoughts into physical things. That's ... I don't know. This is a tricky one. What is the content ... We're making ideas real perhaps.
>
> Interviewer: Hmmm …
>
> **Interviewee:** And that might be what we do... Without, without the thinking that we do, nothing would be created and so that's ... our content is basically we look at anything outside the room or when you're walking down the street you go, "Hey, I look at that" ... and that's what, to me the whole ... the curriculum is trying to promote thinking and innovation ... that's the content.

From the perspective of conducting research in technology education, the previously discussed ecologically situated model and theoretical lenses used in the development of the grounded theory provide a basis for framing research into enacted practice in the subject area. However, consideration should also be given to the grounded theory itself. The approach here may be to design an experimental study, whereby specific subject matter is engaged with via the different conceptions to identify the efficacy of each conception in the learning of specific subject matter. Alternatively, the tensions identified between different application cases and the development of case-independent constructs may also be considered. Further, the utility of the grounded theory in exploring the purposes behind teaching technology should also be emphasised. Specifically, in some national education contexts technology education was introduced to replace previous technical or vocationally oriented subjects. There are notable exceptions whereby technical or craft subjects coexist with technology education on curricula. Investigating the association between the different conceptions identified and the different manifestations of technology education internationally may serve useful in understanding the different statuses held by the technology education subjects.

5.4.2 *The Provision of Technology Education*

As noted previously, during the grounded theory study, a conceptual jump was made to move beyond representations of activity, towards articulating different conceptions of the purpose of teaching technology. Central to this shift in focus was the identification of the theoretical lenses of 'subject matter knowledge in technology education' and the 'role of application case in technology education.' For the majority of interviewees, articulating the specific subject matter appeared to be a challenge, but two approaches emerged through further exploration and probing. Subject matter in technology education was described as either technical knowledge and skills, or a broader understanding of what technology is and how to engage with it. These depictions, like the associations between knowledge and activity, were not mutually exclusive. However, they can be differentiated through how they are defined. Notably, is the subject matter of technology education defined by the technical context or specific application case? Or, does the subject matter stand independent of technical context or application case? The different conceptions identified indicate that both perspectives prevail in current discourse. In particular, the evidence presented suggests a difficulty in bridging to acting in a technological way (conception #2) from technical expertise (conception #1). It is here that one of the most significant implications for teaching technology emerges. Should the teaching of technology be predicated on firstly developing the technical knowledge associated with the context of learning? Evidence from this study, such as teacher's intentional circumnavigation of curricular materials in meeting assessment criteria would indicate that the technical contextual knowledge appears to govern decision making within the classroom, at the expense of achieving the conceptual goals for learning, central to the higher constructs of technological capability and literacy discussed previously. In a similar vein, the conflation of technology with science when a more conceptual approach to the subject was taken suggests that the nature of technology itself is lost within this pedagogical approach. From the provision of technology education perspective (e.g. policymakers, initial teacher education, and technology teachers), the grounded theory presented may be of particular use. As this theory is grounded within reflections on technology education practice in a number of different national education contexts and framed at the level of 'technology education,' it may be of use in analysing prevailing practices in other contexts. Perhaps the most significant implication for teachers is to adopt the presented theory and challenge their assumptions about the nature of technology education.

5.5 How this Research Could be Developed Further

Importantly, as with any constructivist grounded theory, what is presented here should be treated as provisional. This means that conflicting evidence from practice that contradicts the presented theory may be considered valid. Subsequently, this may lead to further clarification or specification of the theory. As previously noted, the utility of the theory presented lies in its capacity to provoke thought about the nature of technology education(s). As such, the grounded theory presented should be of direct use for technology educators. The study utilised conceptions of the purpose of teaching as it allowed individual teachers to hold their purpose for teaching technology in a conceptual space but also articulate more specifically what it is that students are to learn. Through this macro-level approach, the variability of practices which emerged from the literature review as a defining characteristic of technology education was facilitated. Similarly, the decision to strive for a more unified way of framing technology education was taken after the development of the ecologically situated model, and now that this theory is in place, although provisional, attention may be turned specifically to investigating enactment at a micro-level.

A starting point for this investigation may be the ecologically situated model of enacted practice (Fig. 5.1). Through framing a more systematic approach to studying enacted practice and opening a methodological dialogue (Doyle, Seery & Gumaelius, 2019) regarding the design and selection of research methods which facilitate the investigation of the factors identified in the ecologically situated model, this work sought to provoke thought on how to use such research to better understand enacted practices in technology education. The framework and subsequent publication offer a roadmap for technology teachers to investigate their practices. The following areas may be of use for further understandings of our subject:

- Do different technical contexts for technology education lend themselves to alternative conceptions of the subject?
- What emphasis is placed on the application of skills in technology education, and how transferable are these skills to different technical contexts?
- How do technology educators ascribe to the three different conceptions presented?

Acknowledgements I would like to express my sincere gratitude to my supervisors during my studies, Niall Seery, Donal Canty, Lena Gumaelius, and Eva Hartell. I would also like to thank the teachers that provided their time and classrooms for me to conduct the studies. Without you this work quite simply would not have been possible. An electronic copy of the Ph.D. Thesis can be found at the KTH Royal Institute of Technology repository: http://www.diva-portal.org/smash/record.jsf?pid=diva2:1427616

References

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30*(10), 1405–1416.

Atkinson, S. (2017). So what went wrong and why? In E. Norman & K. Baynes (Eds.), *Design Epistemology and Curriculum Planning* (pp. 13–17). Loughborough Design Press.

Banks, F., & Barlex, D. (1999). 'No one forgets a good teacher!': What do "good" technology teachers know? *Journal of Design & Technology Education, 4*(3), 223–229.

Chan, K. K. H., & Hume, A. (2019). Towards a consensus model: literature review of how science teachers' pedagogical content knowledge is investigated in empirical studies. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 3–76). Singapore: Springer. https://doi.org/10.1007/978-981-13-5898-2_1

Dakers, J. R. (2005). The hegemonic behaviorist cycle. *International Journal of Technology and Design Education, 15*(2), 111–126.

Dakers, J. R. (2014). *Defining technological literacy: Towards an epistemological framework* (2nd ed.). Palgrave MacMillan.

de Vries, M. J. (2003). Book reviews. [Review of the book Examining pedagogical content knowledge, by J. Gess-Newsome & N.G. Lederman (Eds.)]. *International Journal of Technology and Design Education*, *13*(2), 196–198.

Doyle, A., Seery, N., Canty, D., & Buckley, J. (2019). Agendas, influences, and capability: Perspectives on practice in design and technology education. *International Journal of Technology and Design Education, 29*(1), 143–159. https://doi.org/10.1007/s10798-017-9433-0

Doyle, A., Seery, N., Gumaelius, L., Canty, D., & Hartell, E. (2019). Reconceptualising PCK research in D&T education: Proposing a methodological framework to investigate enacted practice. *International Journal of Technology and Design Education, 29*(3), 473–491. https://doi.org/10.1007/s10798-018-9456-1

Gess-Newsome, J. (2015). Model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), Re-examining pedagogical content knowledge in science education (pp. 28–42). Routledge.

Gibson, K. (2008). Technology and technological knowledge: a challenge for school curricula. *Teachers and Teaching*, *14*(January 2015), 3–15. https://doi.org/10.1080/13540600701837582

Hyland, Á. (2011). *Entry to higher education in Ireland in the 21st century*. National Council for Curriculum and Assessment and the Higher Education Authority.

Ingerman, Å., & Collier-Reed, B. (2011). Technological literacy reconsidered: A model for enactment. *International Journal of Technology and Design Education, 21*(2), 137–148.

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.

Kelly, A. V., Kimbell, R., Patterson, V. J., Saxton, J., & Stables, K. (1987). *Design and technology: A framework for assessment*. HMSO.

Kennedy, M. M. (2010). Attribution error and the quest for teacher quality. *Educational Researcher, 39*(8), 591–598.

Kimbell, R. (2006). Innovative technological performance. In J. R. Dakers (Ed.), Defining technological literacy: Towards an epistemological framework (pp. 159–178). Palgrave MacMillan.

Kimbell, R. (2011). Wrong … but right enough. *Design and Technology Education: An International Journal, 16*(2), 6–7.

MacAogáin, E. (2005). The points system and grading of the leaving certificate examination. *The Irish Journal of Education/iris Eireannach an Oideachais, 36*, 3–24.

Mioduser, D. (2015). The pedagogical ecology of technology education: An agenda for future research and development. In P. J. Williams, A. Jones, & C. Buntting (Eds.), The future of technology education (pp. 77–98). Springer.

NCCA—National Council for Curriculum and Assessment. (2004). *Review of technology education in the Junior Cycle.*

Petrina, S. (2000). The politics of technological literacy. *International Journal of Technology and Design Education, 10*(2), 181–206.

Ritz, J. M. (2009). A new generation of goals for technology education. *Journal of Technology Education, 20*(2), 50–64.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: an international and interdisciplinary Delphi study. *International Journal of Technology and Design Education*, *21*(4), 409–424.

Shulman, L. S. (1986). Those who understand : Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Spendlove, D. (2012). Teaching technology. In P. J. Williams (Ed.), *Technology Education for Teachers* (pp. 35–54). Sense Publishers.

Spendlove, D. (2015). Developing a deeper understanding of design in technology education. In P. J. Williams, A. Jones, & C. Buntting (Eds.), The future of technology education (pp. 169–185). Springer.

Stables, K. (1997). Critical issues to consider when introducing technology education into the curriculum of young learners. *Journal of Technology Education, 8*(2), 50–65.

Williams, P. J., Eames, C., Hume, A., & Lockley, J. (2012). Promoting pedagogical content knowledge development for early career secondary teachers in science and technology using content representations. *Research in Science & Technological Education, 30*(3), 327–343.

Williams, P. J., Lockley, P. J., & Mangan, J. (2016). Technology teachers' use of CoRe to develop their PCK. In M. J. de Vries, A. Bekker-Holtland, & G. van Dijk (Eds.), *PATT-32 proceedings: Technology education for 21st century skills* (pp. 489–499).

Andrew Doyle After graduating from as a technology teacher in 2015, Andrew began working in Initial Technology Teacher Education. Working at the University of Limerick, he became interested and involved in research, completing his Doctoral Studies at the Department of Learning in Engineering Sciences at KTH Royal Institute of Technology. Andrew is currently a Programme Leader at the Faculty of Construction and the Built Environment in Exeter College.

Part III
Skills in Designing

Chapter 6
Enhancing Elementary Teacher Practice Through Technological/Engineering Design-Based Learning

Anita S. Deck

Abstract As widespread as Science, Technology, Engineering, and Math (STEM) initiatives are today, education programs and school districts in the USA are failing to ensure that elementary teachers have the appropriate knowledge of and proclivity toward STEM subjects. The lack of science instruction and professional development in the United States generates a weakness for both pre-and in-service elementary teachers. Research suggests that one way to address this weakness is through the technological/engineering designed-based approach within the context of integrative STEM education. The purpose of this chapter is to suggest ways in which professional development that educates elementary teachers to implement Technological/Engineering Design-Based Learning (T/E DBL) can enhance their science teaching. The research design was a multiple case study which adhered to a concurrent mixed method approach (Teddlie and Tashakkori, 2006; Yin, 2003). Data collected from surveys were analyzed and corroborated with a sweep instrument, rubric analyses, and interview responses to validate the results. Findings from this study revealed that the professional development model used in this study was effective in getting elementary teachers to implement T/E DBL.

Keywords Technological/engineering design-based learning · Innovation · Science · Integrative STEM education

6.1 Nature of the Problem and Research Questions

In the 1990s, the National Science Foundation began using "STEM" as the acronym for science, technology, engineering, and mathematics. As the use of "STEM" became more prevalent, the acronym became a source of ambiguity. Most, even those in education, say "STEM" when they should be saying "STEM education,"

A. S. Deck (✉)
International Technology and Engineering Educators Association, Concord University, Athens, USA
e-mail: adeck@concord.edu

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_6

overlooking that STEM without education is a reference to the fields in which scientists, engineers, and mathematicians toil (Sanders, 2009). Instead of focusing on defining/redefining STEM, integrative STEM education focuses on new integrative approaches to STEM education and investigates those new integrative approaches. The notion of integrative STEM education includes approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects (Sanders, 2009). This study focuses on utilizing one such integrative approach, Technological/Engineering Design-Based Learning (T/E DBL), to address the lack of science instruction and professional development in both pre-and in-service teachers to effectively teach science in the elementary classroom.

The Next Generation Science Standards (Next Generation Lead States, 2013) derived from A Framework for K-12 Science Education (National Research Council, Committee on Conceptual Framework for the New K-12 Science Education Standards, 2011) require that elementary teachers integrate engineering concepts and practices within their science teaching. However, many elementary teachers have a negative attitude toward science, do not understand it, tend to be anxious about teaching it, and rely heavily on recitation, worksheets, and textbooks to provide the instruction (Mintzes et al. 2012). Science is a way of knowing, a systematic study of the physical and natural world. Science education prepares students to study science at higher levels of education, to enter the workforce, and to become more scientifically literate (National Research Council, 1996; National Research Council, Committee on Conceptual Framework for the New K-12 Science Education Standards, 2011; American Society for Advancement of Science, 1993). Researchers assert that elementary school teachers are not known to be science oriented and merely regard science as a school subject detached from everyday life (Cobern & Loving, 2006). Given the impact that teachers have on the achievement of their students (Gibson & Chase, 2002; Rockoff, 2004; Sanders & Rivers, 1996), teachers' knowledge of science and their attitude toward teaching it should be of considerable concern.

Appleton (2008) stated that rarely do elementary teachers have the opportunity to develop specific discipline pedagogical content knowledge (PCK) because so few develop a science discipline specialization. Many elementary school teachers tend to have limited knowledge in both science content knowledge and in science PCK, given that few elementary school teachers are science discipline specialists (Appleton, 2008).

Traditionally, scientific inquiry has been the effective avenue to help students master science content and develop explanations for the natural world (NRC, 1996/2011; Romberg et al., 2005). To be able to employ inquiry-based teaching practices, elementary teachers must be comfortable with the science content to be taught. Facilitating inquiry-based instruction with frequency and quality has proven a challenging task for many elementary teachers (Adamson et al., 2012; Woodbury & Gess-Newsome, 2002; Yerrick, 2000), and they are further challenged by the expectation to implement reform-oriented practices (Adamson et al., 2012; Barab & Luehmann, 2003; National Center for Education Statistics, 2001). In addition, many of the inquiry-based experiences teachers rely on provide heavy scaffolding in a cookbook-style, step-by-step approach, that directs the sequencing of how any experiment is put together, run, and is used to gather data (Nagle, Hariani, & Siegel, 2006). Hence, studies that consistently reveal problems with elementary science education reflect the science knowledge and practice held by elementary school teachers (Appleton, 2008; Graham et al., 2009; Levitt, 2002).

Technological/engineering design-based learning has been found to be an effective approach in science education (Ercan, & Sahin, 2015; Fortus et al., 2005; Kolodner, 2002; Mehalik et al., 2008; Roth, 2001; Wendell et al., 2014; Leonard & Derry, 2011). T/E DBL provides a reason for learning science content by engaging the student in design and using a natural and meaningful venue for learning both science and design skills (Doppelt et al., 2008; Kolodner, 2002). The potential of teaching science through design-based learning is that the design task provides the context for applying the science knowledge and the science concepts provide a part of the content needed for performing the design task (Sidawi, 2007). Learning science through design activity has been shown to be a productive way to promote deep science learning (Fortus et al., 2004; Hmelo et al., 2000; Kolodner et al., 2003).

Pre-service teachers can typically obtain a license to teach elementary school without taking a rigorous college-level STEM class such as calculus, statistics, or chemistry, and without demonstrating a solid grasp of mathematics knowledge, scientific knowledge, engineering design practices, or the nature of scientific inquiry (Epstein & Miller, 2011). With these recent reforms, it is critical that professional development moves toward more comprehensive designs to account for the minimal teacher preparation in engineering (Bybee & Loucks-Horsley, 2000; Daugherty, 2009). In the future, science assessments will not assess students' understanding of core ideas separately from their abilities to use the practices of science and engineering. They will be assessed together, showing that students not only "know" science concepts; but also, students can use their understanding to investigate the natural world through the practices of science inquiry, or solve meaningful problems through the practices of engineering design (Next Generation Science Standards, 2013).

According to Wells (2014), technological/engineering design-based learning is an instructional approach as well as a pedagogy for teaching core understandings that seek to address a human need by designing a product, system, and/or environment to solve a practical problem. However, purposing and implementing T/E DBL as an instructional approach can elicit teacher concerns. The most critical component in any change initiative is people and identifying how teachers react throughout a change, such as implementing T/E DBL as part of teaching science, is at the heart of the challenge of educational reform (George, 2015; Rogers & Portsmore, 2004).

At the elementary level, the lack of science instruction and professional development resulted in a weakness for both pre-and in-service teachers and prompted elevated concerns about teaching science (Anderson, 2002; Goodrum et al., 1992). Research (Lewis, 1999/2006; Wells, 2014) suggested that one way to address this weakness was through the technological/engineering designed-based approach within the context of integrative STEM education. The goal of this study was to provide evidence supporting the mitigation of elementary teacher concerns toward teaching science, because of professional development on the intentional teaching of targeted science content and practices through the teaching of engineering design content and practices. The purpose was to gain an understanding of change in science instructional content and practice through professional development that educates elementary teachers to implement T/E DBL as part of teaching science. The goals sought to enhance the development of the teaching and learning of T/E DBL and assist in the planning and development of professional development workshops that focus on science teaching and T/E DBL.

To document these changes, the following research questions served as the basis for the study:

After participation in professional development on implementing T/E DBL for intentionally teaching elementary science:

1. What changes in teacher concerns regarding the implementation of T/E DBL were revealed?
2. What change in planning of practice toward the use of T/E DBL was evidenced in teachers' instructional design?
3. To what extent do teachers feel their understanding of the targeted science concepts was positively impacted?

6.2 Research Design to Answer the Questions

The research design was a multiple case study with six participants who were recruited because of their availability and their grade level teaching assignment that correlated to an analysis of the 2013 Virginia science state accountability test, Standards of Learning (Pyle, 2014), which identified science concept weaknesses. Due to unforeseen circumstances, two participants dropped out of the study and the study moved forward with four participants.

Data were generated and collected within each of three research phases: pre-treatment, treatment, and post-treatment. Five instruments were used to collect data to answer RQ1, RQ2, and RQ3: the Stages of Concern Questionnaire (SoCQ), the Instructional Change Indicators (ICI), and the Technological/Engineering Design-Based Learning Lesson Assessment Rubric (LAR), the Understanding of a Virginia Standards of Learning Science Concept Questionnaire, and the Post Interview Protocol.

The three research phases of the study are depicted in Treatment Phases Flow Chart below along with the key Professional Development (PD) activities that occur during each phase.

6.2.1 Treatment Phases Flow Chart

Pre-treatment	Treatment	Post-treatment
Phase 1 (~1 week) a. Prior Understanding VA Science SOL Questionnaire b. SoCQ administration c. Unit 1 submission d. ICI/LAR analysis	**Phase 2**: PD1 (~1 week) a. Teach the processes and strategies of T/E DBL b. Revise and submit Unit 1 c. ICI/LAR analysis of Unit 1 **Phase 2**: PD2 (~2 weeks) a. Individual PD feedback session on ICI /LAR analysis b. Design and submit Unit 2 c. ICI/LAR analysis of Unit 2 **Phase 2**: PD3 (~2 weeks) a. Individual PD feedback session on ICI/LAR analysis b. Implement Unit 2 c. Based on implementation, revise and submit Unit 2	**Phase 3** (~3 days) a. SoCQ administration b. Post Understanding VA Science SOL Questionnaire c. Post interview d. ICI/LAR analysis of Unit 2

Through experiential learning, participants were presented with a task situated in a real-world context incorporating the science concept, *identify possible impacts of human activity on the ecosystem*, and gain an understanding of T/E DBL from a learner's perspective. This science concept was identified as a weakness for fourth and fifth grade students in a southeastern state. The traditional STEM education models did not suffice in conveying the conceptual and/or pedagogical approach of Integrative STEM Education (Wells, 2016). The model used as the Professional Development Plan in this study is the PIRPOSAL Model: Conceptual/Pedagogical Framework of Integrative STEM Education (Wells, 2016).

6.3 Treatment: Professional Development Plan

Problem Identification: Quarrying rocks and minerals has been a significant resource for building human infrastructure for thousands of years. Quarrying is the process of obtaining resources found on or below the land surface. Water is used for tasks such as cutting with high-pressure jets and the lubrication of solid cutting tools. As a result, nearly all mining processes generate vast amounts of wastewater. Wastewater can also include additional contaminants of unnatural substances, like oil and gas from machinery, and natural sediments in excessive quantities. To help reduce the amount of contaminated waste water dumped into the environment, we have partnered with Water Works Technology to design a system to clean the waste water in one of the small accumulation ponds (30 feet by 15 feet) for The Agate Company. Besides the area of the pond itself, there is an 8-foot-wide area around the edge of the pond available for use. The Agate Company intends to use the treated wastewater to be used as a water source for plant life when they reclaim the quarry site. Therefore, the treated wastewater must meet the environmental requirements for supporting plant life. The company's budget does not allow for the treatment to exceed $10,000.

Challenge: Design a working prototype of a system that will clean the wastewater in a small accumulation pond.

Ideation (I). In the Ideation phase, the participants work in dyads to generate ideas for possible solutions for wastewater treatment. Usually, this process also illuminates what is known and unknown about wastewater and wastewater treatment and may occur concurrent with the Research phase. Participants summarize their brainstorming ideas either in a narrative or graphic form.

Research (R.). Due to the technological and biological components of the problem, the participants must address each to inform their possible solutions. Any information that may edify their solutions should be recorded.

Potential Solutions (P.). By analyzing the ideas generated and the information gathered through research, participants explore the feasibility of possible solutions to the treatment of the wastewater. Participants should develop detailed sketches and notes of their purposed solutions.

Optimize (O.). The dyads experiment and explore their purposed solutions and determine their best idea considering elements such as time, resources, criteria, and constraints. After agreeing on a solution, participants construct a working prototype of their system to treat the wastewater.

Solution Evaluation (S.). Participants test their design solution using the design criteria as testing criteria. Data should be collected, recorded, and analyzed for evaluation. Participants should create a summary of this analysis.

Alterations (A.). Participants use the results from their evaluation to make adjustments to their design solution. The results may lead them to revisit their potential solutions for another iteration of their design. Iterations should be recorded.

Learned Outcomes (L.). Each dyad presents their design solution through verbal and visual presentations detailing their design process. The participants are provided with a list of questions to address during their presentation.

The purpose of Phase 1: Pre-Treatment was to establish a baseline for data collected throughout the study. The Pre-Treatment included (a) administration of the Understanding of a Virginia Science Standards of Learning questionnaire, (b) administration of the SoCQ, (c) the collection of the participants' lesson plan (Unit 1) used to teach the targeted science concept during the previous year, and (d) analysis of submitted units using the ICI and LAR instruments.

The purpose of Phase 2: Treatment, involving three separate PD sessions, was to collect the data necessary to answer RQ2.

- Phase 2: PD1
  - (a) Participants received targeted professional development via an immersion experience using T/E DBL
  - (b) Participants revised Unit 1 to reflect the use of this strategy
  - (c) Submission of their lesson for ICI and LAR analyses

- Phase 2: PD2
  - (a) PD session to provide participants with feedback on Unit 1 based on the ICI and LAR analyses
  - (b) Participants designed and submitted Unit 2 which targeted a new science concept
  - (c) ICI and LAR analyses of Unit 2
- Phase 2: PD3
  - (a) Participants provided with feedback in an individualized PD session
  - (b) Implementation of Unit 2 in the classroom
  - (c) Revision and submission of Unit 2 for ICI and LAR analyses

The purpose of Phase 3: Post-Treatment completed data collection for the study, answered research questions, RQ1, RQ2, and RQ3, and involved (a) the administration of the SoCQ, (b) the administration of the Understanding of a Virginia Science Standards of Learning Questionnaire, (c) the administration of the Post Interview Protocol and (d) the ICI and LAR analyses of Unit 2 for use of the T/E DBL.

To examine the data collected from the SoCQ to answer RQ1, all participant responses were analyzed to determine whether participant concerns changed significantly from Phase 1 to Phase 3. To address RQ2, the results of the ICI and the LAR were analyzed for correlation with change in instructional design.

To inform RQ3, the data generated from participant responses from the pre-and post-tests Understanding of a Virginia Science Standards of Learning Questionnaire were analyzed. Theme analysis was used to examine participant interview responses from the Post Interview Protocol to identify, analyze, and report patterns that emerge within the collected data, illuminate participant rating choice, and further expand on participant rating scores.

6.4 Results of the Study

The professional development model investigated through this study was demonstrated to be effective in assisting elementary teachers to implement T/E DBL. Data showed that following the PD, participants were better able to integrate T/E DBL when planning and designing instructional units and demonstrated an improved understanding of the science concepts they were teaching.

The first research question (RQ1) driving this study asked, “What changes in teacher concerns regarding implementation of T/E DBL are revealed” following targeted professional development. Overall, the consensus data showed a trend toward mitigation of internal concerns following T/E DBL professional development, and therefore can be concluded that the PD did have some positive impact on alleviating concerns.

To determine whether the PRE/POST changes in teacher concerns toward the innovation were statistically significant, a paired sample *t*-test was conducted on the mean group scores for each of the seven stages of concern of the SoCQ. Results of this analysis indicated there was no statistical group difference PRE/POST in participants' internal concerns (stages 0–3), nor in their external concerns (stages 4–6). Based on analysis of these data, the overall group results would imply that the treatment did not significantly mitigate participants' concerns toward the innovation.

As would be expected with innovation, the PRE profile reflected a typical high level of internal concerns and a lower level of external concerns. The expectation in this study was that after the treatment, internal concerns would drop while external concerns would elevate. However, the POST group profile in Fig. 4 is atypical in showing no relative changes between levels of internal or external concerns.

Recognizing the sample size in this study was extremely small, finding there was not a typical SoCQ group effect was expected. Given the results of the group data analysis, the profile generated did not exhibit the typical SoCQ profile pattern, and therefore, was not particularly useful for the purpose of the study. Considering this and given the case study approach which was used to guide this research, generating individual participant profiles proved to better demonstrate the influence of the T/E DBL treatment. Hence, a qualitative examination of each participants PRE/ POST data was conducted to generate individual profiles and discern any changes in internal and/or external concerns post intervention.

By examining the interview analysis and demographics of individual participants and determining outside influences, data indicate that the PD had an overall positive impact on mitigating internal concerns than their SoCQ profile alone would indicate. In the case of Participant B, the pre/post SoCQ profiles demonstrating consistently high internal concerns, coupled with results of interview data analysis revealing concerns about continued employment, give some justification for elevated internal concerns about the innovation before and after PD. Participant C had only been teaching for five years and had little experience in teaching science, thus the "novice" status of this participant is a variable that likely contributed to the anomaly of high Informational and Personal internal concerns.

The second research question (RQ2) guiding this study queried, "What change in planning of practice toward use of T/E DBL is evidenced in teachers' instructional design" following participation in professional development. Data resulting from the lesson sweeps using the T/E DBL Instructional Change Indicators (ICI) and the T/E DBL Lesson Assessment Rubric (LAR) were analyzed to determine changes in instructional design of participant units to address RQ2. Although both instruments were designed with multiple data categories, only data from the T/E DBL Phase Integrations category of the ICI and the Instructional Design T/E PIRPOSAL Model category of the LAR were needed to address RQ2. The concurrent analyses of data from just these two categories were needed to arrive at a final determination of change in practice toward the use of T/E DBL. The remaining categories on the ICI and LAR did not have any bearing on corroborating the integration of T/E DBL phases.

The units developed/revised by all participants consistently increased in the percent of phase integration and level of engagement across both units. Prior to treatment, two participants integrated at least one T/E DBL phase engagement in one lesson of the initial draft of Unit 1. Additionally, one participant included five phases integrations into a lesson and one participant did not include any phase integrations in Unit 1 Initial. By the conclusion of the T/E DBL PD, all four participants had integrated five or more engagement phases (≥62%) in at least three lessons in Unit 2 Revised while three participants incorporated all eight phases (100%) in two or more Unit 2 Revised lessons. The results showed a range of 25% to 100% for percent of phase integration after treatment.

From an examination of the findings, the researcher concluded that the PD was effective in changing the participants' instructional design use of T/E DBL phases of engagement to intentionally teach the targeted science concepts. This is evidenced by the increasing number of T/E DBL phases of engagements used in the revision of Unit 1 and the design and revision of Unit 2 as captured by the sweep instrument.

Additionally, the conclusion is supported by the instructional design change shown through the comparison of PRE and POST unit designs. Participants expanded the number of lessons in the planning of Unit 1 from a few lessons to a more robust five lessons in their revision. This deliberate planning continued in Unit 2 whereby the rubric assessment revealed the participant used a preponderance of T/E DBL engagement phases in each lesson included in the unit.

The third and final research question (RQ3) of the study asked, "To what extent do teachers feel their understanding of the targeted science concepts was positively impacted" following participation in professional development. Data results used to inform this question were collected from two sources, the Understanding of a Virginia Science Standard of Learning (SOL) Questionnaire and the Post-Treatment Interview. Participants completed the Understanding of a Virginia Science Standard of Learning Questionnaire before and after the implementation of the T/E DBL PD. The questionnaire was administered before the T/E DBL PD treatment began and then again eight weeks later at the conclusion of treatment.

As with the SoCQ data, "group comparisons" were not the best reflection of the PD impact. Therefore, calculating individual participant changes provided a more accurate indicator, and was more in line with the Case Study methodology. Based on the post survey responses and interview data, the conclusion drawn is that T/E DBL PD, as implemented, does have a positive impact on increasing an elementary teachers' understanding of a targeted science concept students are expected to demonstrate, and belief in their ability to teach the targeted science concept.

In drawing this conclusion, it is important to note that although a few participant responses on the Understanding of a VA Science SOL Questionnaire indicated no change in understanding, during post interviews participants explained that they *thought* they understood the target science concepts before participating in the PD. However, upon completion of the PD, they realized their understanding of the targeted science concepts was incomplete and that the PD provided the clarification needed to fully understand the science concepts.

The findings from the research study are based on four case studies, and therefore, is limited to only those participants that were involved in the study. Within these limitations, the conclusions reached regarding the use of T/E DBL as an effective pedagogical approach for elementary science and technology education have specific implications for: (a) in-service professional development providers; (b) pre-service preparation programs; and (c) researchers. Thus, the implications presented here are reflective of the participants of the study.

1. For in-service professional development providers and pre-service preparation programs of science and technology education, the PD model presented in the study has strong potential for affecting a positive change in elementary science teaching practice through T/E DBL. By presenting science in the context of an authentic engineering design challenge using the PIRPOSAL model, teachers are more able to design units that promote higher-order thinking and intentionally teach science within a "need to know" context (Wells, 2014).
2. For researchers of science and technology education, the PD model presents a useful model for producing measurable outcomes of change in elementary science teaching practice and T/E DBL. The instrumentation used in the study provides several data collection points and serves to corroborate findings.
3. Given these results pertaining to mitigating internal concerns, data suggested that the PD model is effective in identifying concerns teachers may have about implementing T/E DBL. Therefore, in-service professional development providers and pre-service preparation programs can adjust the PD to improve the overall fit of the model tailored to participant needs.
4. The positive impact of the PD on teacher understanding of the targeted science concepts implies the effectiveness of the model when teaching science concepts through T/E DBL to elementary teachers. For in-service professional development providers and pre-service preparation programs, using the PD model not only addresses teacher understanding and teaching of the science content, but also comprehending student performance of the concept.

6.5 Implications to Improve Teaching and Learning

The professional development model investigated through this study was demonstrated to be effective in getting elementary teachers to implement T/E DBL. Data showed that following the PD, participants were better able to integrate T/E DBL when planning and designing instructional units, and demonstrated an improved understanding of the science concepts they were teaching.

Within the limitations of the study, the conclusions reached regarding the use of T/E DBL as an effective pedagogical approach for elementary science and technology education have specific implications for: (a) in-service T/E DBL professional development providers; and (b) T/E DBL teachers. Thus, the implications presented in the following section are reflective of the participants of the study.

1. For in-service professional development providers and teachers of science and technology education, the PD model presented in the study has strong potential for affecting a positive change in elementary science teaching practice through T/E DBL. By presenting science in the context of an authentic engineering design challenge using the PIRPOSAL model, teachers are more able to design

units that promote higher-order thinking and intentionally teach science within a "need to know" context (Wells, 2014). By design, the PD model is student-centered and student-driven, and gives space for teachers to meet the needs of students in a variety of ways. Rather than teaching isolated concepts, teachers build upon prior knowledge when possible. Rice and Kitchel (2016) stated that teachers should be provided with more opportunities to explore integrating students' prior knowledge into the curriculum, through design-based learning approaches.

In addition to teaching science within a "need to know "context, teachers also can provide students with "just-in-time delivery." Teachers are encouraged to reject the urge to convey all the information they know to their students. TE/DBL can allow for effective differentiation in instruction and learning as well as the learning environment. Regardless of grade level, TE/DBL is accessible and equitable to several types of diverse learners.

2. When deciding how to provide professional development, as well as what professional development is needed and offered, it becomes even more imperative that all educators receive the professional development that considers the needs of all stakeholders, which includes teachers, as well as their students (Bullard et al., 2017). The PD model is not a "one size fits all" model. Given the results pertaining to mitigating internal concerns, data suggests that the PD model is effective in identifying concerns teachers may have about implementing T/E DBL. Therefore, in-service professional development providers can adjust the PD to improve the overall fit of the model tailored to participant needs.

Guskey (2003) stated that the characteristics that influence the effectiveness of professional development are multiple and complex. It may be unreasonable, therefore, to assume that a single list of characteristics leading to broad brush policies and guidelines for effective professional development will ever emerge, regardless of the quality of professional development research. The SoCQ can provide the necessary data for PD providers to address participants concerns when planning instruction.

3. The positive impact of the PD on teacher understanding of the targeted science concepts implies the effectiveness of the model when teaching science concepts through T/E DBL to elementary teachers. For in-service professional development providers and teachers, using the PD model not only addresses teacher understanding and teaching of the science content, but also comprehending student performance of the concept. Professional learning that has shown an impact on student achievement is focused on the content that teachers teach. Content-focused PD is most often job embedded, meaning the PD is situated in teachers' classrooms with their students, as opposed to generic PD delivered externally or divorced from teachers' school or district contexts. This type of PD can provide teachers the opportunity to study their students' work, test out new curriculum with their students, or study a particular element of pedagogy or student learning in the content area (Darling-Hammond, Hyler, & Gardner, 2017).

In their study, Freeman et al. (2014) indicate that active learning increases student performance by half of a letter grade. Teachers' understanding of the nature and purpose of content strongly influences their personal pedagogical content knowledge, i.e., what they deem as important. This means that teachers need to have a sense of what the nature of the content is, understanding its organizing concepts as well as its tools. Therefore, they can teach students to locate and build knowledge on their own.

6.6 Recommendations for Practitioners

Based on the findings of this study, the following presents recommendations for STEM and elementary science teacher educators, and in-service professional development providers regarding the improvement of the teaching of science content and planning of practice through the implementation of technological/engineering design-based learning.

A critical component in any change initiative is people and identifying how teachers react throughout a change, such as implementing T/E DBL as part of teaching science, is at the heart of the challenge of educational reform (George, 2015; Hord, Rutherford, Huling-Austin, & Hall, 1987). An administration of some type of survey, such as the SoCQ, mid-treatment could be useful in directing the PD model for individuals. This allows teacher educators to determine the direction for in-service activities. Professional development providers can design additional strategies for those individuals in need of intervention and identify target groups for more intensive efforts. The additional survey administration could provide information for planning support services when implementing T/E DBL in the classroom during the final phase of the PD model.

Profession development sessions must provide knowledge about the science concept (or technology, engineering, or mathematics concepts) as well as explicitly demonstrate the T/E DBL phases of engagement to teach science content and design instruction. Professional development is significantly influenced by the teacher's ability to teach science concepts. Knowing the teacher's experience level in teaching science and their belief in their ability is essential to the success of the PD sessions. To be effective in the classroom, accomplished teachers need to have a strong command of the subject matter they teach. Research after research has indicated that pedagogical content knowledge is the basis for effective teaching. However, knowledge is not stagnant. As quickly as information and technology evolve currently, it is essential that teachers stay abreast of evolving trends and developments in their areas of expertise—this is true for what they teach—content—and how they teach it—pedagogical knowledge. Because of this, learning should not be limited to new teachers, but for all teachers regardless of where they are in their career. Therefore, targeted content specific professional development is essential for classroom teachers.

Classroom observations were not a part of this study but could provide valuable feedback information on the implementation of T/E DBL in the classroom and teacher practice. These observations could assist in identifying challenges and strengths of implementation and practice that can be addressed during follow-up professional development sessions. Classroom observations can make educators more aware of how they behave in the classroom and of the needs of students in their classroom while implementing T/E DBL, and can also be used to stimulate dialog and discussion. Classroom observations can provide a framework for giving constructive and focused feedback that helps teachers incorporate higher levels of desired knowledge into their instruction (Stuhlman et al., 2015).

6.7 Developing the Research Further. Action Research Suggestions for Teachers

For action researchers of STEM and elementary science education, the PD model presents a useful model for producing measurable outcomes of change in elementary science teaching practice and T/E DBL. Following are recommendations for further research because of the findings and conclusions of this study.

Action researchers could replicate this study by incorporating the strategies of the PD model using the same data instruments described. To successfully replicate the study, a multiple case study is essential due to the small sample size. The multiple cases could be achieved if the sample size consists of teachers from the same grade level within the same school or district. Challenges do exist with using the same data instruments used in the study. The scale of the Lesson Assessment Rubric (LAR) used in this study is too expansive and does not provide an accurate reflection of a participants' progressive use of T/E DBL engagement phases.

Use a rubric, such as the Instructional Change Indicators and Lesson Assessment Rubric, and focus solely on T/E DBL. Customize an existing rubric by eliminating unnecessary categories and revise the score sheet to reflect only the T/E DBL phases of engagement and instructional design. If using The Lesson Score Sheet from this study, then the score sheet should be reduced to Instructional Design, T/E: PIRPOSAL with the following rating scale: Lesson Plans: 1–2 Points (Revisions needed); 3–4 (Implement without revisions). However, be aware that by not including the additional categories and rating scales, the participants may not incorporate the other design elements into their unit or lesson plan.

Develop a questionnaire that surveys the understanding of the state standard containing the science concept to be taught. Sample questions could be as follows: 1. How well do you understand the standard stated? 2. How well do you understand the science concept in this standard that students are expected to demonstrate? 3. How well do you understand the instructional requirements for teaching the science content in this standard? This question order allows the participant to first explore their understanding of student performance of the science concept which prepares them to contemplate their ability to teach the science content based on that student performance.

Classroom observations. An analysis of classroom observations using a protocol, such as the Reformed Teaching Observation Protocol (RTOP), could be conducted to provide more detailed and precise evidence of change. Additionally, these observational studies would provide a coherent, well-substantiated knowledge base about effective T/E DBL and improve the PD model.

Teachers are likely to resist an innovation unless they are convinced there are benefits for their students and they have a role in the process (Gusky, 2003; Rogers, 2003). The recommendations presented here can assist with creating a dialog between STEM and elementary science teacher educators, in-service professional development providers, and the in-service and pre-service teachers they seek to instruct and pave the way for effective classroom implementation. In addition, when individual teachers or a group of teachers make a personal commitment to systematically collect data on their work, they are embarking on a process that will foster continuous growth and development toward integrative STEM education. In this way, these teachers conducting action research are making continuous progress in developing their strengths as reflective STEM education practitioners.

References

Adamson, K., Santau, A., & Lee, O. (2012). The impact of professional development on elementary teachers' strategies for teaching science with diverse student groups in urban elementary schools. *Journal of Science Teacher Education, 24*(3), 553–571.

American Society for Advancement of Science. (1993). *Benchmarks for Science Literacy, Project 2061*. Washington, DC: Author.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1–12.

Appleton, K. (2008). Developing science pedagogical content knowledge through mentoring elementary teachers. *Journal of Science Teacher Education, 19*, 523–544.

Barab, S. A., & Luehmann, A. L. (2003). Building sustainable science curriculum: Acknowledging and accommodating local adaptation. *Science Education, 87*(4), 454–467.

Bullard, M., Rutledge, C., & Kohler-Evans, P. (2017). Using the Stages of Concern Questionnaire to ensure professional development with teachers and teacher candidates. *International Research in Higher Education., 2*, 50. https://doi.org/10.5430/irhe.v2n4p50

Bybee, R. W., & Loucks-Horsley, S. (2000). Advancing technology education: The role of professional development. *The Technology Teacher, 60*(2), 31–34.

Cobern, W., & Loving, C. (2006). Culturally important issues and science: A gender and science-interest investigation. *International Journal of Human Sciences*, *3*.

Darling-Hammond, L., Hyler, E., & Gardner, M. (2017). Effective teacher professional development. Palo Alto, CA: Learning Policy Institute.

Daugherty, J. (2009). Engineering professional development design for secondary school teachers: A multiple case study. *Journal of Teachnology Education, 12*(1), 10–24.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education, 19*(2), 22–39.

Epstein, D., & Miller, R. T. (2011). Slow off the mark: Elementary school teachers and the crisis in science, technology, engineering and math education. Washington, DC: Center for American Progress.

Ercan, E., & Sahin, F. (2015). The usage of engineering practices in science education: Effects of design based science learning on students' academic achievement. *Necatibey Faculty of Education, 9*(1), 128–164.

Fortus, D., Dershimer, C., Krajcik, J., Marx, R., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110.

Fortus, D., Dershimer, C., Krajcik, J., Marx, R., & Mamlok-Naaman, R. (2005). Design-based science and real-world problem-solving. *International Journal of Science Education, 27*(7), 855–879.

Freeman, S., Eddy, S., McDonough, M., Smith, M., Okoroafor, N., Jordt, H., & Wenderoth, M. J. (2014). *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

George, L. J. (2015*). Concerns of elementary school leaders and teachers when implementing a common core aligned mathematics program* (Doctoral dissertation). Retrieved from, http://surface.syr.edu/cgi/viewcontent.cgi?article=1209&context=etd.

Gibson, H. L., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education, 86*(5), 693–705.

Goodrum, D., Cousins, J., & Kinnear, A. (1992). The reluctant primary school teacher. *Research in Science Education, 22*, 163–169.

Graham, R. C., Burgoyne, N., Cantrell, P., Smith, L., St Clair, L., & Harris, R. (2009). Measuring the TPACK confidence of inservice science teachers. *TechTrends, 53*(5), 70–79.

Guskey, T. (2003). Professional development that works: What makes professional development effective? *Phi Delta Kappan, 84*(10), 748–750. https://doi.org/10.1177/003172170308401007

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of Learning Sciences, 9*(3), 247–298.

Hord, S. M., Rutherford, W. L., Huling-Austin, L., & Hall, G. E. (1987). Taking charge of change. Alexandria, VA: ASCD.

Kolodoner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education*, *39*(3).

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design™ into practice. *Journal of the Learning Sciences, 12*(4), 495–547.

Leonard, M. & Derry, S. (2011). What's the science behind it? The interaction of engineering and science goals, knowledge, and practices in a design-based science activity (WCER Working Paper No. 2011–5). University of Wisconsin-Madison.

Levitt, K. E. (2002). An analysis of elementary teachers' beliefs regarding the teaching and learning of science. *Science Education, 86*(1), 1–22.

Lewis, T. (1999/2006). Research in technology education–Some areas of need. *Journal of Technology Education, 10*(2), 41–56.

Mehalik, M., Doppelt, Y., & Schunn, C. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71–85.

Mintzes, J. J., Marcum, B., Messerschmidt-Yates, C., & Mark, A. (2012). Enhancing self-efficacy in elementary science teaching with professional learning communities. *Journal of Science Teacher Education, 24*(7), 1201–1218.

Nagle B., Hariani, M., & Siegel, M. (2006). Achieving a vision of inquiry: Rigorous, engaging curriculum and instruction. In R. E. Yager (Ed.) *Exemplary Science in Grades 5-: Standards-Based Success Stories*. Arlington, VA: National Science Teachers Association Press.

National Center for Education Statistics. (2001). Teacher preparation and professional development: 2000. Washington, DC: US Department of Education, Office of Educational Research and Improvement.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press

National Research Council, Committee on Conceptual Framework for the New K-12 Science Education Standards. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academy of Sciences.

Next Generation Science Standards Lead States. (2013). *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.

Pyle, E. (2014). *2013 VISTA standards of learning state accountability test results*. Charlotesville, VA: Author.

Rice, A., & Kitchel, T. (2016). Influence of knowledge of content and students on beginning agriculture teachers' approaches to teacher content. *Journal of Agricultural Education, 57*(4), 86–100.

Rockoff, J. E. (2004). The impact of individual teachers on student achievement: Evidence from panel data. *American Economic Review*, 247–252.

Rogers, E. M. (2003). *Diffusion of Innovations*, 5th edn. NewYork: Free Press

Rogers, C., & Portsmore, M. (2004). Bringing engineering to elementary school. *Journal of STEM Education, 5*(3), 17–28.

Romberg, T. A., Carpenter, T., & Dremock, F. (Eds.). (2005). *Understanding mathematics and science matters*. Mahwah, NJ: Lawrence Erlbaum Associates.

Roth, W. M. (2001). Learning science through technological design. *Journal of Research in Science Teaching, 38*(7), 768–790.

Sander, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, December/January.

Sanders, W. L., & Rivers, J. C. (1996). *Cumulative and residual effects of teachers on future student academic achievement (Research Progress Report).* Knoxville, TN: University of Tennessee Value-Added Research and Assessment Center.

Sidawi, M. M. (2007). Teaching science through designing technology. *International Journal of Technology and Design Education, 19*(3), 269–287.

Stuhlman, M. W., Hamre, B. K., Downer, J. T., & Pianta, R. C. (2015). *How classroom observations can support systematic improvement in teacher effectiveness.* Charlottesville, VA: The Center for Advanced Study of Teaching and Learning.

Teddlie, C., & Tashakkori, A. (2006). A general typology of research designs featuring mixed methods. *Research in Schools, 13*(1), 12–28.

Wells, J. (2014). Integrative STEM education: U.S. educational reform, pedagogical commons, design based biotechnology literacy exemplar. In *Proceedings of the 60th Anniversary International Elementary Education Conference on Issues and Prospects for Sustainable Integrative Education in the 21st Century*. Seoul, South Korea: Seoul National University of Education.

Wells, J. G. (2016). PIRPOSAL model of integrative STEM education: Conceptual and pedagogical framework for classroom implementation. *Technology and Engineering Teacher, 75*(6), 12–19.

Wendell, K., Kendall, A., Portsmore, M., Wright, C. G., Jarvin, L., & Rogers, C. (2014). Embedding elementary school science instruction in engineering design problem solving. In Ş. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices* (pp. 143–162). Purdue University Press. Retrieved from, http://www.jstor.org/stable/j.ctt6wq7bh.11.

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the paradox of change without difference: A model of change in the arena of fundamental school reform. *Educational Policy, 16*(5), 763–782.

Yerrick, R. K. (2000). Lower track students' argumentation and open inquiry instruction. *Journal of Research in Science Teaching, 37*(8), 807–838.

Yin, R. K. (2003). *Applications of Case Study Research.* Thousand Oaks, CA: Sage.

Anita S. Deck Anita is an associate professor at Concord University in the Education Department of the College of Professional Studies. She prepares elementary and secondary teacher candidates for teacher licensure. Anita's educational efforts in pedagogical content knowledge are guided by a research theme in integrative STEM education. She is the former Director of Innovation,

Assessment, and Research at ITEEA's STEM Center for Teaching and Learning. A former public school teacher with 13 years of experience, Anita completed her doctoral degree at Virginia Tech where she served as the Curriculum Specialist for the Virginia Initiative for Science Teaching and Achievement.

Chapter 7
Teaching Science Through Design Activities

Dave van Breukelen

Abstract Curricula increasingly embrace interdisciplinary learning. In case of science and technology it provides a holistic approach comparable to how both domains interact in daily life. It can help make learning authentic, meaningful, and motivational. Design-based learning (DBL) offers such an approach, based on strong pedagogical foundations, where students must apply knowledge and skills to solve design problems by designing an artefact that meets specific needs and requirements. As a result, students become highly skilled, but the complexity of design seems to interfere with conceptual learning. Scaffolding and explicit teaching strategies help to solve this problem. By analysing a requested design, it is possible to unravel what specific content is connected to the design problem (backward design). This helps to deduce learning outcomes and to develop the learning task. By doing this, a final design challenge addresses a complete and coherent knowledge framework (content scaffolding). Specific teaching guidelines help teachers to cope with the dynamic learning process by proceeding in sufficiently small steps and checking for understanding (instructional scaffolding). Through explication of fundamental knowledge and continuously de- and re-contextualisation (to other contexts), students acquire a conceptual framework that can be used in different contexts (knowledge transfer). Overall, a pedagogical strategy arises that facilitates learning by sufficient focus, thorough Investigation of what must be learned, informed application of content during technological design, and creating synergy between science and technology.

Keywords Design-based learning · FITS model · Concept learning · Science · Technology

D. van Breukelen (✉)
Fontys University of Applied Sciences for Teacher Education Sittard, Eindhoven, the Netherlands
e-mail: d.vanbreukelen@fontys.nl

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_7

7.1 The Question I Asked and Why It Is Important

Modern societies are strongly dominated by a complex, interdisciplinary world in which science and technology have an increasing impact on our personal lives: the length and quality of life, changes in moral values, the way we communicate, travel and work, etc. Most of the world's issues require application of a complex blend of skills and knowledge and we might expect school systems to respond accordingly by adapting their education. Unfortunately, many curricula are still dominated by monodisciplinary subjects, like physics, technology, biology, and mathematics. Science subjects are often designed around sterile, dehumanised content with little attention to important practices. Subjects related to technology often suffer from a lack of conceptual enclosure. Design activities, for example, frequently serve as instructional strategy imbued with trial and error. Aikenhead (2006) states that monodisciplinary curricula result in sterile content that has little appeal to students, which is confirmed by international studies, e.g. Organisation for Economic Cooperation and Development (2019), and demonstrate a decreasing interest in and understanding of science and technology.

Other studies suggest that interdisciplinary teaching, with attention to authentic, challenging, and relevant contexts, may improve motivation and understanding (Rennie et al., 2012). Such properties can be found in how (design) technology initiates goal-directed, purposeful activities in which knowledge (e.g., conceptual, procedural) and skills (e.g., design, experimentation, craft) are used to solve problems and meet human needs. Hence, this similarity has been used to create design-based learning (DBL) approaches that merge science and technology: design-based modelling, engineering for children, engineering competitions, informed design, design-based science and learning by design. They all apply similar design strategies. First, students address design problems by exploration to identify what they need to do. Second, students try to find answers to design-related research questions coming from the exploration. Third, answers help students to create design solutions after which prototyping, and design realisation takes place. Fourth, through testing, evaluation, iteration and redesign a solution arises.

By analysing DBL research many similarities arise. Nearly all approaches create meaningful, stimulating learning environments in which process-orientated learning is highly stimulated due to a strong focus on what to do and deliver, which results in significant improvements of design, metacognitive and collaboration skills. Unfortunately, despite DBL's strong pedagogical foundations, nearly all approaches struggle with conceptual learning. Students are often unable to explain artefact performance by using scientific and technological principles. Measured levels of conceptual understanding, based on pre-post-test data, show low gains that also seem highly teacher dependent (Wendell, 2008). Students show little rationale for how to connect design decisions to essential concepts. Hence, if we could manage a conceptual design approach where, for example, scientific knowledge is strongly involved, DBL becomes a catalyst for interdisciplinary teaching. Thus, the main goal of the research was to investigate why DBL's nature interferes with concept learning and strongly intertwined, how to improve concept learning, resulting in the following central research question: Why does the current practice of DBL not yet lead to an expected high level of concept learning, and how can learning be enhanced resulting in a strategy where the learning of concepts and skills both are strongly represented?

7.2 How I Tried to Answer the Question

To study conceptual learning issues the Learning by Design (LBD) approach was chosen as a starting point (Kolodner et al., 2003). LBD has been studied extensively in the past and produced rich data on student learning and LBD's strengths and weaknesses, accompanied by transparent descriptions of data collection and analysis. In the new research, four cohesive studies, see Fig. 7.1, were developed where the emphasis shifted from qualitative to quantitative data (Van Breukelen, 2017).

The first study addressed two sub-questions: When do students use scientific concepts for design purposes and how do students demonstrate conceptual understanding? What learning strategies, which can enhance conceptual learning, are missing and how this absence affects learning? To provide some focus the hypothesis

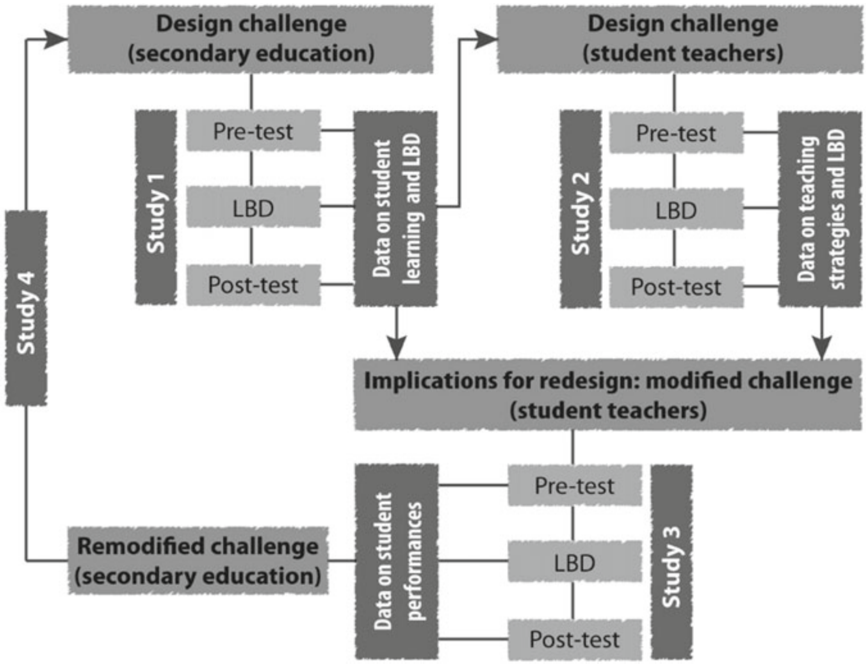

Fig. 7.1 Overview of studies

was formulated that the complex nature of design, due to many objects of integration and strong process focus, forces students to overlook conceptual knowledge and to focus on doing rather than knowing. Then, because previous studies were designed around pre-and post-testing, a detailed analysis of the LBD process took place through sound recordings, observations, questionnaires, and interviews. For this, a traditional LBD task was developed, specified in Table 7.1, and guided by three experienced teachers, that took six class periods of 100 min each. Seventy-seven general secondary education students, aged 13–14 and working in design

Table 7.1 LBD's stages and activities

Stages	Activities[a]	Products[b]
1. Introduction (20–30 min)	Introduction of task, activities, organisation, learning sources, objectives, etc. (C)	
2. Understanding the task, messing about, whiteboarding (50–60 min)	• Exploration of task, context and objectives (G) • Writing down ideas, (research) questions and hypotheses (G) • Whiteboarding: sharing insights, feedback (C)	Design diary stage 2 • Flip chart, whiteboarding (G)
3. Investigate and explore, poster session (120–180 min)	• Formulate and distribute (scientific) research questions (C) • Discussion of "fair testing" (C) • Design and conduct experiments, collect data, conclude (G) • Presentation: poster and feedback session (C) • Discussion of results: redoing/adjustments (C/G)	Design diary stage 3 • Final research questions (C) • Fair test rules of thumb (C) • Laboratory notebook (G) • Poster (G)
4. Establishing design guidelines (20–30 min)	• Formulating guidelines by using research results (C) • Focus on science: use of scientific concepts (C)	Design diary stage 4 • Design guidelines (C)
5. Design planning, pin-up session (80–90 min)	• Devise, share and discuss solutions: divergent thinking (G) • Poster: provisional design solution (G) • Pin-up (poster) en feedback session (C) • Adjusting provisional design solution (G) • Redoing until satisfied: final design solution (C/G)	Design diary stage 5 • Design posters (G) • Design sketch (G)
6. Construct & test, analyse and explain, gallery walk (120–180 min)	• Prototyping and design realisation (G) • Testing designs based on design specifications (G) • Gallery walk: determine deficiencies, feedback/reflection (C) • Discussing points of improvement (C/G)	Design diary stage 6 • Prototype (G)

(continued)

Table 7.1 (continued)

Stages	Activities[a]	Products[b]
7. Iterative redesign (60–120 min)	• Iteration of steps depending on decisions made (C/G) • Improving the design (G) • Final discussion of design solutions and functionalities (C)	Design diary stage 7 • Final solution (G) • Final reflection (individual)

C = class activity/product; G = design group activity/product

[a] Resources: ELE, smartphones, laptops, tablets, Microsoft Office® software, interactive simulation, internet access, materials and tools for design realisation and conducting experiments

[b] Design diary (ELE-archived): reflections, feedback, descriptions, and pictures/movies. Bullets are stage specific

groups of 3–4 students, were challenged to design a battery-operated dance pad that let them use their feet to sound buzzers or flashlights. The dance pad had to consist of four self-designed, operating floor pads and one ready-to-use main power switch. The most fundamental design principles concerned proper wiring (combining series and parallel parts) and the use of conducting and insulating materials for floor pad creation. To investigate and design circuits students used real experiments and simulation software (PhET™ DC-circuit construction kit). Participants had prior experiences regarding characteristic LBD practices, but students had no specific prior knowledge regarding electric circuits.

The second study focussed on teaching because the literature claims that learning outcomes are strongly teacher dependent (Bamberger & Cahill, 2013) and teachers involved in Study 1 experienced many difficulties. The following sub-questions were leading: What teaching strategies dominate and (directly) affect conceptual learning and to what extent these strategies take place? Which strategies should get more attention to enhance concept learning? To provide answers, a second LBD task was developed, based on Table 7.1, for six first-year pre-service science teachers where they had to design a highly efficient solar power system for a model house. Design specifications stimulated creative thinking and decision-making and confronted design groups with content, like physical aspects of electric circuits, circuit calculations, solar cell behaviour, and the concepts of current, voltage, energy, and power. The challenge, which lasted three successive days, was guided by two teacher trainers and interviews, video and sound recordings enabled in-depth study of teacher behaviour.

Studies 3 and 4 focussed on the enhancement of concept learning by translating the results of Studies 1 and 2 into pedagogical (re)modifications. For this, a final pair of sub-questions were formulated: How the pedagogical structure of DBL activities can be improved based on previous studies? To what extent concept learning and the learning of skills is affected? The traditional LBD tasks developed for Studies 1 and 2 were (re)modified and used again. For Study 3, in which 21 pre-service science teachers took part, the solar house challenge was enriched by explicit teaching and scaffolding strategies. Based on results, two more modifications, regarding reduced fragmentation, were added which resulted in a modified dance pad challenge, tested with 237 general secondary education students and five experienced teachers. All (re)modifications are explained in Table 7.2.

Table 7.2 LBD (re)modifications

Modification	Underpinning (■) and implementation (●)
Comprehensiveness of science content by BACKWARD DESIGN	■ Task analysis to predict learning outcomes by unravelling weakly and strongly related concepts. Underexposed concepts, complementing the knowledge domain, were addressed by additional (teacher-driven) interventions. A more detailed description of backward design will be given in the next section ● Effects of resistance and potential differences on circuit operation were underexposed. Through simulation software, students already used for circuit exploration, and information seeking students had to study circuit operation by a varying number of lights and batteries. Class discussion was used to deepen insights
Implementation of GUIDED DISCUSSION to explicate science	■ Guided class discussions aim to highlight and explicate underlying science. By observing students' thinking and doing during collaboration it becomes clear what students understand about science. Then, (in)correct insights are used to discuss (mis)conceptions and to head for proper reasoning and understanding ● Class discussions were orchestrated by guided discussion
INFORMED DESIGN for creating a conceptual design approach	■ Informed design activates, enhances, and broadens prior knowledge through preparatory activities, which enhances design realisation by conceptual enclosure ● Students additionally had to explore, during exploration, prior knowledge based on scientific, task-related terminologies and questions. By information seeking and group discussion they discussed cognitive gaps

(continued)

Table 7.2 (continued)

Modification	Underpinning (■) and implementation (●)
EXPLICIT INSTRUCTION AND SCAFFOLDING to facilitate teaching	■ A series of scaffolds to guide students through the learning process by proceeding in small steps, checking for understanding, active participation, and clear statements about purposes of and rationales for learning activities. In addition to the adjustments in this table that also fit into this category, teacher handling was improved by using clear strategies ● Teachers were informed about teaching strategies, how to use and apply them, and stimulated to use them, which contributes to more balance between process guidance and concept learning
SCIENCE LECTURES to explicate and transfer conceptual knowledge	■ Related science is discussed explicitly, based on a complete and coherent picture of science involved and with particular attention to conceptual relations. First, within the design context and, second, by de- and re-contextualisation to other contexts to enhance knowledge transfer ● Two traditional science lectures were added: after experimentation (before designing) to facilitate a conceptual design approach and at the end to discuss designs scientifically
AMALGAMATION to stimulate the ongoing learning process	■ Reduction of (separate) stages to offer more coherence and less administration where guidance and scaffolding shifted towards the ongoing process rather than breaking it down into parts ● The number of stages reduced from seven to four and administrative moments from six to two, resulting in two investigation-dominated phases and two design-dominated phases

7.3 What I Found Out

Students in Study 1 were able to manage medium–low conceptual performances, which is comparable to findings of Kolodner et al. (2003). These disappointing performances were still far from high gains managed through, for example, Interactive Engagement (IE) physics courses (Hake, 1998). Remarkably, IE and DBL have many similarities: problem-based, student-centred, heads- and hands-on connections, classroom discussions, feedback sessions, collaboration, and reflective moments. However, IE contains less integrative elements and more teacher guidance, and therefore seems less complex. This may support the hypothesis that the complex nature of design forces students to overlook conceptual knowledge. Especially, because students in Study 1 were process and product focussed (What to do and deliver?) and data analysis revealed this was primarily provoked by the complexity and extensiveness of the challenge. Students learned scientific concepts explicated by the teacher (often unplanned), concepts that strongly determined design realisation and content important for completing assignments. For example, simulation software and real experiments provided insight in electrical wiring, teacher-guided interventions and class discussions helped students to learn about scientific terminologies and circuit operation, and assignments asked students to explore electrical symbols and circuit diagrams. In general, the more concepts directly determined task completion the better concepts were understood. Consequently, ad hoc exploration and use of science caused implicit learning, resulting in an incoherent and incomplete picture of underlying science based on isolated facts. Although students learned scientific terminologies and designed proper electric circuits, they failed to demonstrate proper scientific reasoning and did not achieve deep conceptual understanding.

Study 2 showed that explicit teaching strategies, teacher feedback and activities strongly related to design realisation, like solar cell measurements, were highly appreciated by students for learning concepts. Especially, when interventions directly appealed to underlying science or facilitated the ongoing learning process. Unfortunately, only 13% of all teacher interventions concerned these topics and, besides, many interventions took place unplanned or by chance. From a teaching perspective and in conjunction with Study 1, preparatory task analysis is necessary to predict (conceptual) learning outcomes. Depending on the requested design, it must become clear what concepts are strongly addressed by the task and what concepts are weakly task related and should be addressed otherwise (teacher-driven) to complement the conceptual framework. Based on this analysis, the design task can be enriched by additional activities or interludes to enhance concept learning by offering a complete and coherent conceptual framework and thorough explication.

Studies 3 and 4 showed that the (re)modifications in Table 7.2, which represent the findings of Studies 1 and 2, enabled a significant increase of the concept learning level. Students were able to equal achievements found in IE courses: nearly a doubling of learning gains found in Studies 1 and 2. This conceptual performance was accompanied by large increases in achievement levels among seven skill dimensions (negotiations, distribution of tasks/efforts, use and adequacy of prior knowledge, scientific reasoning, experimentation, and self-checks), which is comparable to traditional LBD research. Furthermore, the study revealed strong positive correlations between concept learning and three skill dimensions: use and adequacy of prior knowledge and scientific reasoning. By combining (re)modifications and the traditional LBD approach a promising DBL strategy arises where students learn through providing a proper task Focus, investigating scientifically what must be and learned, informed application of content during Technological design activities, and creating and explicating Synergy regarding science and technology (FITS). In general, the FITS model, which will be discussed in the next section, provides an answer to the main research question, and enables us to share some important implications.

7.4 How This Might Be Used to Improve Teaching and Learning

7.4.1 Heading for Design as a Teaching Method

For a smooth introduction of DBL, its complexity, as pointed out before, should not be underestimated. Depending on teaching and learning experiences, educational level, and prior knowledge and skills, it is necessary to choose an approach that smoothly develops competences before addressing complex design tasks. Figure 7.2 shows how this can be done. When teachers and/or students are inexperienced designers, it is necessary to firstly address knowledge and skill builders. For example, during reversed design students explore an object unknown to them and they try to extract design specifications and functionalities: they learn to think like a designer. Thinking challenges stimulate divergent thinking and creativity: for example, ask students to explore as many ways as possible to close a door automatically after it has been opened manually. Secondly, students and teachers explore fundamental parts of the design process through cycle zooming, after which larger design problems can be faced. For example (type C), present students a real artefact, designed by other students, including original design specifications and ask them to test and assess the artefact and to provide suggestions for improvement. Hence, start with defined learning tasks that enable teachers and students to get familiar with design as a learning strategy and gradually add more complexity (scaffolding).

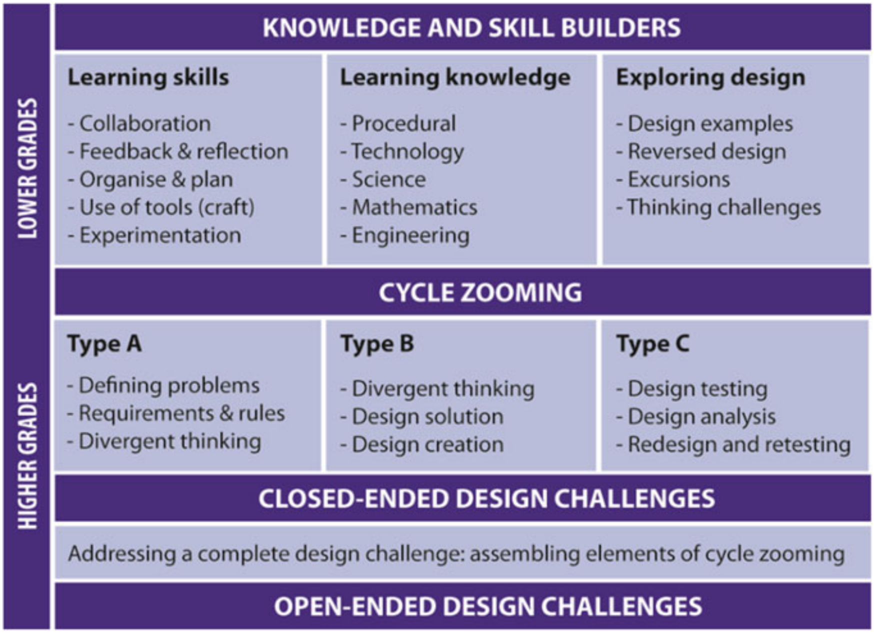

Fig. 7.2 Curriculum approach for DBL

7.4.2 Backward Design to Develop Design Tasks

When students and teachers get used to design as a teaching approach, it is possible to introduce simple design tasks. For example, provide students with paper sheets and paperclips and ask them to design an aeroplane that flies as far as possible. Then, students will mostly focus on shape and aerodynamics because that is their frame of reference (strongly related). They will hardly search for other important insights that may help them to improve the design. They want to produce and deliver! As a result, and as discussed before, students develop an incomplete and fragmented conceptual framework. To prevent this from happening, the strategy of backward design, already addressed in Table 7.2, becomes important. A crucial element for a smooth flight, often unknown to students and therefore weakly-related, is the position of the centre of gravity, which can be improved by adding paperclips to the front of the plane. To pop up this important feature, it may help to show a video of a flying aeroplane that suffers from sliding cargo. Then, students may recognise the disturbed movement of the real plane in their paper aeroplane (transfer), which introduces the concept of centre of gravity.

Thus, a crucial step to create design tasks and to enhance conceptual enclosure and knowledge transfer is to ensure sufficient content scaffolding. As illustrated in Fig. 7.3, each potential design idea should be the starting point for learning task construction. An in-depth analysis of designs and their crucial elements reveal which

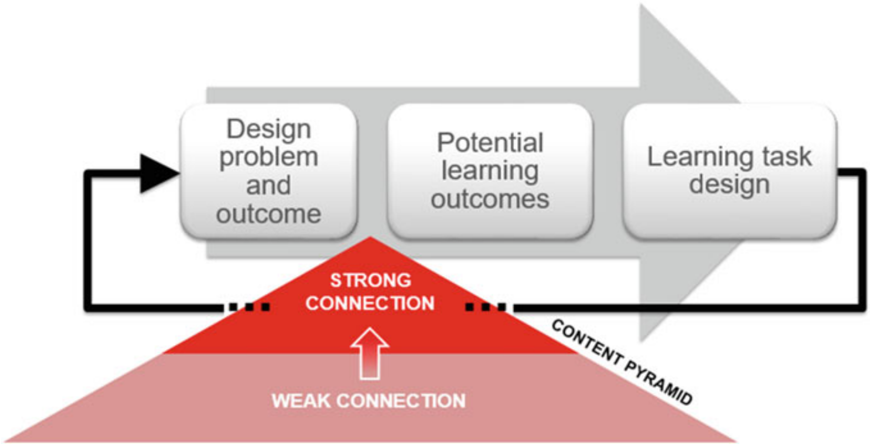

Fig. 7.3 Learning task construction through iterative backward design

content underlies successful design realisation (content pyramid) and, in relation to students' prior knowledge and skills, which content is weakly or strongly related. Then, it is possible to establish potential learning outcomes and to enrich design activities by additional, pre-planned interventions like experimentation, class discussions, information seeking, demonstrations, etc. Hence, iterative backward design enables teachers to design learning tasks that address a complete and coherent framework of content, which enhances conceptual learning and informed design realisation. Studies 2 and 3 offer another example of how additional (teacher-driven) activities can enhance the informed design. Students were asked to design a highly efficient solar power system for a model house. Students in Study 2 incorrectly assumed, without testing, that solar cells behave like voltage sources; the only frame of reference they had. This assumption resulted in insignificant and time-consuming experimentation and design realisation by trial and error. To prevent this from happening, students in Study 3 were asked, as an additional activity, to measure and study solar cell characteristics. This enabled students to develop proper insights for design creation.

7.4.3 An Approach for DBL: FITS Model

By expanding the necessities for the paper aeroplane challenge (paper sheets and paperclips) with, for example, wooden skewers, elastic bands and/or tape it is possible to add more complexity. Students can be challenged to design strong bridges or towers and the number of design specifications can be increased. The more complexity increases the need for more scaffolding and explication of content and processes. This stresses the importance of proper investigation before design realisation takes place. By combining LBD and studied (re)modifications (Table 7.2), a design approach

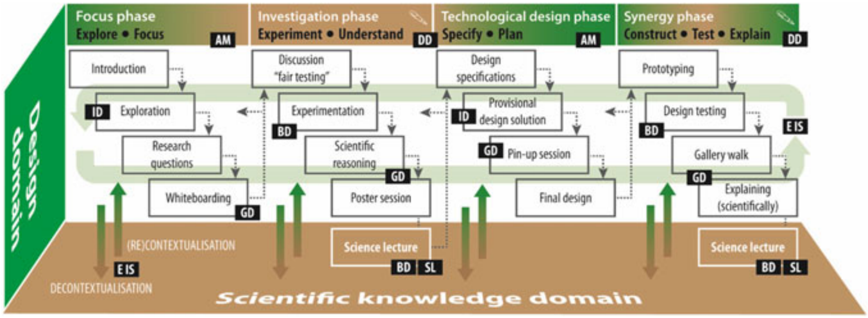

Fig. 7.4 FITS model and (re)modifications

arises, visualised as the FITS model in Fig. 7.4, that offers teachers a starting point to create complex DBL tasks. The rectangular activities in the white part are traditional LBD components but, for the purpose of amalgamation (AM), the model combines them in four stages and two moments of administration when students must complete a partly pre-structured design diary (DD). By doing this, keeping LBD's seven stages and administrative moments in mind, more coherence is offered, and administration is limited to the amount necessary to move on. Furthermore, the colour gradient shows how an initial design focus (green) can lead to design solutions by explicitly addressing the science domain (brownish) and, by doing that, making the FITS model a catalyst for interdisciplinary teaching: design provides the direction towards solid learning outcomes by a scientifically paved road.

As shown in Fig. 7.4, additional activities that enable informed design (ID), deduced through backward design (BD), especially seem to fit in with design exploration, experimentation, creating design solutions, design testing and science lectures (SL). Although those activities enrich the process and enable content scaffolding, more is necessary to reach knowledge transfer. Important content should be explicated and enriched (teacher-driven) by examples of de- and re-contextualisation (to other contexts). Explication can be done by anticipating the process and during pre-planned activities, like experiments, lectures, additional interludes, and class discussions. For class discussions, guided discussion (GD) helps to discover what students understand about science. By continuously observing students' thinking and doing, and by discussing (in)correct insights explicitly, scientific reasoning and understanding can be enhanced. The FITS model contains four fixed moments of class discussion.

- Whiteboarding: sharing insights and questions coming from the exploration through whiteboard or flipchart notes.
- Poster session: presenting research results and answers to (research) question through a poster.
- Pin-up session: presenting initial design ideas by sharing drawings, sketches, notes, considerations, uncertainties, etc.

- Gallery walk: presentation and explanation of the design realisation, room for assessment.

The traditional science lectures provide a complete and coherent picture of the content involved, where especially during the synergy phase it also becomes explicit how science and technology complement and enrich each other.

Although Fig. 7.4 implies a chronological order of preference, the arrows stress the importance of iteration and offer the possibility to change direction. It is even possible, especially when students become skilled designers, to prefer a concentric approach in which students can make their own choices and can change directions and skip activities. Thus, Fig. 7.4 should be seen as an overall picture rather than a mandatory approach that always should be applied.

7.4.4 Teaching Strategies

Besides content scaffolding, teacher guidance is also crucial to the success of DBL and requires explicit instruction and scaffolding strategies (EIS, Fig. 7.4). Strategies that facilitate teachers to face the open-ended nature of design, to relinquish directive control and to teach with attention to sensitive assistance (Murphy & Hennessy, 2001): intervene when necessary and hold back when possible. As discussed before, the research invested in developing such a framework, which is shown in Table 7.3. The framework contains five categories within three interaction types where a distinction is made between skills emerging during the activity, induced by the intervening teacher (anticipatory skills), and skills important for task construction and preparation (preparatory skills). The more strategies are located at the bottom of the table, the more they are appreciated by students in facilitating concept learning. Especially, when interventions directly address underlying knowledge (e.g., scientific reasoning, experimentation, teacher-led class discussions). Students also highly appreciate interventions that stimulate an ongoing learning process (e.g., clear instructions, process feedback, equipment of the learning environment). In addition to Table 7.3, it is worthwhile to discuss the most important pitfalls that were seen during the research because discussing them is the first step in preventing them from occurring.

1. Teachers often, more than necessary, demand an overkill of administration, and its use for learning purposes seems limited. Hence, link administration to critical moments, keep it to a minimum and use it to improve learning (e.g., reflective notes). Suggestion: during moments of class discussion, write down feedback directly on, for example, posters and whiteboards and enable digital archiving through taking pictures of the outcome.
2. Teachers have difficulties in applying sensitive assistance. They often correct (potential) mistakes prematurely and provide direction and solutions without substantiation. In general, they interfere with the students' thinking process (too quickly).

Table 7.3 Learning-related interactions and teaching strategies

Interaction	Categories and teaching strategies (A: anticipatory skill; P: preparatory skill)
1. Student (to student) interaction	Collaboration A—Stimulate collaboration: students must be the first point of call A/P—Stimulate and (partially) obligate students to draw/sketch A/P—Ensure availability of materials/tools (and stimulate to use them) P—Collaboration should be organised in advance by a fixed structure
	Reflection A—Stimulate reflective thinking: ask questions that excite reflection A/P—Stimulate students to base (future) handling on reflection A/P—Attend to the fact that reflection should focus on knowledge, skills, attitudes, failures and successes P—Provide learning tasks with fixed moments of well-structured reflection
2. Student to teacher interaction	Teacher and peer feedback A—Be sure to give proper, timely feedback A—Do not be a problem solver but act like a resource: redirect and provide tips/hints A/P—Ensure feedback serves as input for reflection and future actions P—Organise fixed moments for providing and receiving feedback
	Explicit teaching A—Stimulate students to think aloud A—Conscientiously use, connect, and repeat proper (scientific) terminologies and insights emerging from the task and make them explicit A/P—Use moments of feedback and reflection as explication tools A/P—Explicate extensive and complex elements in smaller units P—Discuss all learning objectives and content knowledge explicitly
3. Student to content interaction	Process-related issues A—Do not correct mistakes prematurely but provide them with feedback A—Prevent time pressure: use constructive feedback for encouragement A/P—Take care of clear instructions and (high-quality) learning materials and encourage students to use them P—Build in multiple contexts in which the same concepts occur

3. It is a challenge to keep actively involved and to take all teaching guidelines into account. As a result, process progress and delivering products becomes dominant and hinders (potential) learning outcomes. 87% of all observed teacher interventions were process-related instead of content-related. Thus, teachers show the same tendency as students intuitively have strong process and poor content focus.
4. Teachers continuously seem to struggle with time issues, which has several consequences. It feeds the second and third pitfall and prevents teachers from explication and addressing additional activities for anchoring knowledge. Therefore, it is necessary to design learning tasks well informed and with care: use available time effectively.

7.5 Conclusion

The main conclusion is that teachers are crucial to the success of DBL. Firstly, because of its open-ended nature, which demands explicit instruction and scaffolding strategies (Table 7.3) to provide sensitive assistance. Secondly, because DBL activities should be carefully planned and designed based on various conditions, like educational level, prior knowledge and skills, school context, etc. In all, the teacher's role should (partly) shift from restricted to extended professional as shown in Fig. 7.5. Teachers should decide, based on their own and students' experiences and competences and by taking Fig. 7.2 into account, how to introduce and expand DBL in their educational context. They must search for existing learning tasks that are amenable to DBL and adapt them when necessary. Adjustments, based on backward design, might be desirable, for example, to enrich the task content, to meet contextual or local circumstances, to reach specific learning goals, to take account of available resources, etc. The goal is to improve the learning process and to expand DBL experiences in size and complexity. Eventually, it might even be necessary that teachers must create DBL activities or tasks themselves.

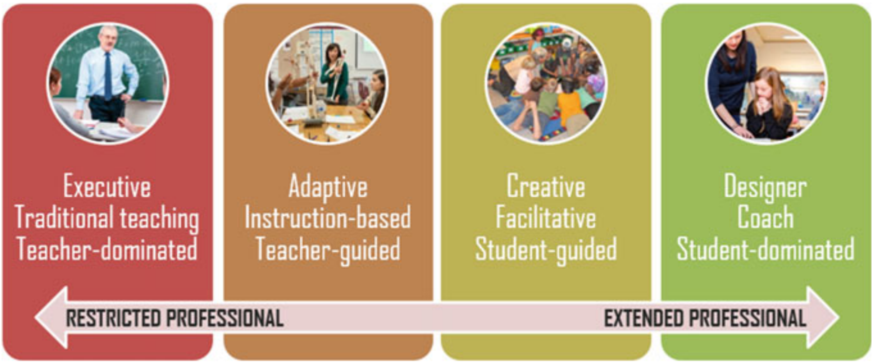

Fig. 7.5 Restricted versus extended professional

7.5.1 How This Research Could Be Developed Further?

This research, like much other research, used multiple choice tests to assess conceptual learning. Unfortunately, these tests may fail to uncover conceptual understanding because knowledge structures remain invisible (Stoddart et al., 2010). Therefore, in Studies 3 and 4, concept mapping was used, in addition to multiple choice testing, to assess conceptual understanding. Study 3 revealed promising correlations between both test methods but significant lower gains for concept mapping. Students in the fourth study, who were less familiar with mapping techniques, struggled to deliver proper concept maps at all. In all, it is an important challenge to explore and investigate possibilities to accurately assess conceptual understanding.

A second research topic directly appeals to teachers' crucial role in the success of DBL. Improving the pedagogy of DBL only makes sense when (future) teachers can adjust to a new kind of classroom control. This research focussed on how and what students learn through DBL and what teaching strategies seem important; symbolised by the blue circle (learning students) and green circle (teaching skills) of the educational Venn diagram in Fig. 7.6. More research is necessary into the topic of learning teachers, which can result in a high-level DBL training programme. This may complete the Venn diagram and, according to Feiman-Nemser (2012), enable a solid anchoring of DBL in educational practice.

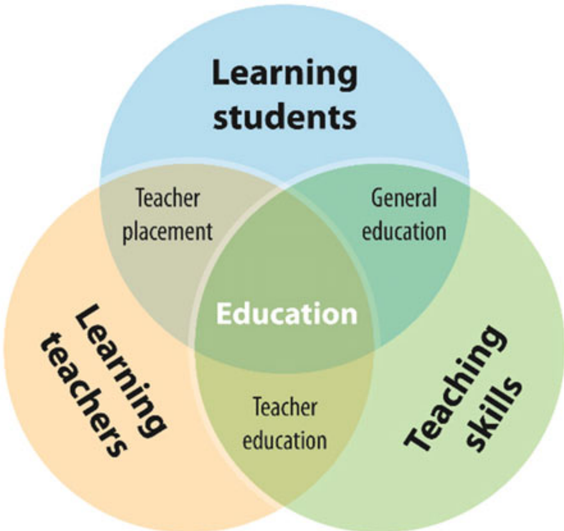

Fig. 7.6 Educational Venn diagram

7.5.2 Research Suggestion for Teachers

Many examples of DBL tasks are available and many have written about its potential. However, each educational context is exposed to a lot of various interactions and conditions that can interfere with learning and teaching. Hence, the biggest challenge for teachers is to cope with impediments and difficulties, to show perseverance and, finally, to explore and embrace DBL. Be open minded, investigate opportunities, embrace iteration, and collaborate with colleagues and experts. For example, team teaching, which enables practitioners to learn by induction, might be crucial to enhance the quality of design-based teaching and learning. Gradually, when more iterations and experiences take place, practitioners become familiar with DBL which enables them to cope with a broad range of DBL settings.

References

Aikenhead, G. (2006). *Science education for everyday life. Evidence-based practice.* Teachers College Press.

Bamberger, Y. M., & Cahill, C. S. (2013). Teaching design in middle-school: Instructors' concerns and scaffolding strategies. *Journal of Science Education and Technology, 22*(2), 171–185.

Feiman-Nemser, S. (2012). *Teachers as learners.* Harvard Educational Publishing Group.

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64–74.

Kolodner, J. L., Gray, J. T., & Fasse, B. B. (2003). Promoting transfer through case-based reasoning: Rituals and practices in learning by design classrooms. *Cognitive Science Quarterly, 3*(2), 1–28.

Murphy, P., & Hennessy, S. (2001). Realising the potential—And lost opportunities—For peer collaboration in a D&T Setting. *International Journal of Technology and Design Education, 11*, 203–237.

Organisation for Economic Cooperation and Development. (2019). *PISA 2018 results (Volume I): What students know and can do.* https://doi.org/10.1787/5f07c754-en

Rennie, L., Venville, G., & Wallace, J. (2012). *Integrating science, technology, engineering, and mathematics.* Routledge.

Stoddart, T., Abrams, R., Gasper, E., & Canaday, D. (2010). Concept maps as assessment in science inquiry learning—A report of methodology. *The International Journal of Science Education, 22*(12), 1221–1246.

Van Breukelen, D. (2017). *Teaching and learning science through design activities. A revision of design-based learning.* Doctoral dissertation. Science Education & Communication, Delft University of Technology, Delft (NL).

Wendell, K. B. (2008). *The theoretical and empirical basis for design-based science instruction for children.* Unpublished Qualifying Paper. Tufts University.

Dave van Breukelen was born on the 21st of May 1980 in Sittard, The Netherlands. In 2001 he obtained a bachelor's degree in physics education and started working as a physics teacher at various educational levels. In 2005 he obtained a master's degree in physics education and since August 2007 he has worked at the Fontys University of Applied Sciences for Teacher Education Sittard as a teacher educator (physics and technology) and researcher. This initiated the start and completion of a PhD project on design-based learning at the Delft University of Technology, which was funded by the Netherlands Organization for Scientific Research (NWO).

Chapter 8
Human-Centered Design Pedagogies to Teach Values in Technology Education

Neshane Harvey and Piet Ankiewicz

Abstract Technology is value laden; hence technology education should create opportunities for students to learn about and practically apply value judgements to enable them to become future agents of change. Over the past three decades the rationale to include values, especially moral values, in technology education has gained increased momentum. Incorporating values in technology education would prevent the discipline from becoming mere technical education. *The exploration of the context for designing and making* is one stage in the technological process to support students' exploration of value judgements. The current orthodox pedagogy should be replaced by one in which values relating to technology and technology education are co-constructed rather than imposed. Hence, a new pedagogy known as co-design is proposed. Co-design is an approach to human-centered design (HCD). Co-design is acknowledged as a novel design field which sees the user as a valuable contributor to counterbalance the values of the 'hero-designer.' Co-design can be applied as a pedagogy in design and technology education. However, design education is critiqued for the lack of opportunity for collaboration because of disciplinary silos even though the process begins with understanding core values of inclusion and questioning the notion of who designs in the age of collaboration. For co-design, the core values of inclusion and collaboration imply partnerships with users. Hence, co-design pedagogy aligns with technology education in socially constructed values which are inter-subjective and co-constructed. The first part of the chapter deliberates on a co-design pedagogy in fashion design education and findings revolving around three design principles emanating from HCD interventions, namely: (1) users as core and inspirational source, (2) design with users, and (3) identify user needs for integration with design. These three design principles act as input for design action, planning and making. Discussion then shifts to the second part where linkages are drawn to propose strategies for including the teaching of moral values in technology education.

N. Harvey (✉) · P. Ankiewicz
University of Johannesburg, Johannesburg, South Africa
e-mail: neshaneh@uj.ac.za

P. Ankiewicz
e-mail: pieta@uj.ac.za

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_8

Keywords Human-centered design · Co-design pedagogy · Values · Design and technology education · Fashion design education

8.1 The Question We Asked and Why It is Important

The rationale to include values in technology education has been established by scholars in the field (Barlex, 1993; Breckon, 1998; Conway, 1994; Holdsworth & Conway, 1999; Layton, 1991; Martin, 2002; McLaren, 1997; Middleton, 2005; Pavlova, 2005; Prime, 1993; Rekus, 1991; Riggs & Conway, 1991). Thus, technology education should create opportunities for students to learn about and practically apply value judgements to enable them to become future agents of change. According to Martin (2002), *the exploration of the context for designing and making* is one stage in the technological process to support students' exploration of value judgements. Dakers (2005) argues that orthodox pedagogy should be replaced by one in which values relating to technology and technology education are co-constructed rather than imposed. Hence, a new pedagogy known as co-design is proposed.

Co-design, sometimes known as participatory or collaborative design, is an approach to human-centered design (HCD). Although HCD may be viewed the same as user-centered design, scholars argue that HCD reflects humanness and a "concern for people" with users becoming joint partners whereas user-centered design merely indicates "people's roles as users" therefore users are considered as study subjects (Sanders & Stappers, 2012; Steen, 2011: 45). Co-design is acknowledged as a novel design field which sees the user as a valuable contributor to counterbalance the values of the 'hero-designer' (Ordaz et al., 2018; Stables, 2017). Design scholarship strengthened the argument of the "designer as special and his skills unique" but design criticism patterned itself on art criticism which rejoiced the 'hero-designer' and disregarded the user (Baynes, 2010: 26).

Hence, co-design can be applied as a pedagogy in design and technology education (Ordaz et al., 2018). However, Fleming (cited in Stables, 2017: 65) critiques that design education lacks opportunity for collaboration because of "reinforced disciplinary silos" even though the process begins with understanding core values of inclusion and questioning "who designs" in the age of collaboration. This implies that co-design pedagogy aligns with Dakers (2005) positioning of technology education in socially constructed values which are inter-subjective and co-constructed.

Co-design, as a new pedagogy is grounded within Martin's (2002) stage: *the exploration of the context for designing and making*. This stage is relevant because at this stage in the design process, students can explore and socially co-construct value judgements with users to counterbalance personal values that inform later stages. The first part of this chapter deliberates on a co-design pedagogy in fashion design education at a university level. The authors acknowledge that fashion design education may well include subject matter relating to moral value constructs of ethics and sustainability for application into design and making activities. Co-design is a social sustainability angle, and it is these students who learn about such value judgements who may well apply HCD principles to design and making activities. Hence, it is possible for fashion design education to transform but a shift in mind-set and pedagogical methodologies is required to ensure that students learn to design with the needs and values of people through co-design. HCD might add value to pedagogical activities and the teaching of values but locally and internationally, fashion design education appeared as an under-developed research area (Harvey et al., 2019a, b). From an HCD lens, fashion design education also lacks academic investigation as well as practical guidelines for teaching and learning (Harvey, 2018). However, HCD is relevant given the call to move towards co-design and collaboration in design and technology education. This research gap and rationale led to the research question: what are the pedagogical strategies and underlying design principles of a HCD approach and its effects to fashion design education at a university level? Effects refer not to cause-effect relations but to participant views and experiences. Similarly, although contextualised within university fashion design education due to the context-specific nature of the research design, this new pedagogy may well be applicable to the teaching of values in school-context design and technology education.

8.2 How We Answered the Question

The methodology employed qualitative design-based research (Amiel & Reeves, 2008; Collins et al., 2004; Plomp, 2010; Reeves, 2006) embedded in an interpretive paradigm via social constructivist methods. The scholarship of HCD was reviewed to define design principles of HCD for teaching and learning interventions. Although several design principles emerged, three are considered for this chapter namely: (1) users as a core and inspirational source, (2) design with users, and (3) identify user needs for integration with design. The first design principle (DP1) serves as input or the starting point, the second (DP2) is about collaboration and the third (DP3) relates to user needs as value judgements. These three design principles of HCD specifically link to *the exploration of the context for designing and making* and were used to design two teaching and learning interventions (known as the pilot and main interventions respectively). Both interventions took the form of design projects, for implementation with first-year fashion design students at a South African urban university. The design projects served as the assessment method revolving around the assessment instruments: (1) a design journal to record, justify and make explicit all design and development activities, (2) a two-dimensional artistic fashion illustration and technical drawings of the final design solution, (3) three-dimensional prototypes and (4) a three-dimensional manufactured, wearable product.

To engage with *the exploration of the context for designing and making*, students could not apply secondary visual inspiration and manifestations of personal values and self-expression. Rather, pedagogical strategies required students to role-play in design teams of two where one student assumed the role of designer and the other that of user with autonomy to select design team members and respective roles.

The intention was to create a culture of teaching and learning about the needs and values of users to combine with that of the designer. Therefore, pedagogical strategies required design teams to: (1) engage in qualitative discussions to establish the context of design use, user needs, preferences, goals, and design requirements, and (2) in collaboration, co-design and develop a product with the user. Although HCD requires collaboration with actual users, the guidelines of studio-based pedagogy paved the way to simulate a co-design situation.

A purposive sample of participants entailed three participant sub-sets, namely first-year fashion design students as well as two university educators (educators used to represent university lecturers) who taught either design or product development activities to first-year students. Additionally, the main author served the dual role of primary observer by collecting data during the teaching and learning interventions, and secondary participant by designing both pilot and main interventions in collaboration with both educators. All participants granted informed consent for qualitative data collection which entailed participant observation, student semi-structured questionnaires and educator semi-structured interviews. Participant observations aimed at exploring and documenting, on pre-drafted observational schedules, design team's design process activity tasks and how these actions extended in *the exploration of the context for designing and making*. Participating students self-administered hard-copy questionnaires aimed at ascertaining their views and experiences regarding the design principles of HCD. Similarly, individual, digitally recorded, face-to-face, semi-structured interviews were conducted with the two educators.

Data were analysed via a constant comparative method (Merriam, 2009) with the application of Atlas.ti. Data analysis followed Saldaña's (2016, p. 14) "streamlined codes-to theory" model via first and second coding cycles. However, data collection and coding emerged simultaneously because the findings from the pilot intervention informed the design of the main intervention.

8.3 Findings

The findings are narrated around the above-mentioned three design principles of HCD. To support the findings, participant data quotations are included. Letters and numbered codes are assigned as pseudonyms to differentiate between participants. For example, E2 represents educator number two, SU1 signifies student user response, while SD1 is the student designer in the same design team. PO reflects participant observation field notes.

8.3.1 Users as Core and Inspirational Source

Findings around users as core and inspirational source were previously deliberated (Harvey et al., 2019a) but for this chapter, discussion pertains to values. Discussion begins by highlighting a shift in mind-set which led to the value judgement of design with empathy. Thereafter, deliberations shift to designer and user views (students role-playing) to validate that empathy does manifest when users are placed as core and inspirational source to drive design because designers and users place themselves in the lived experience of the other person.

Designers found users as core and inspirational source as "eye-opening" (SD6) to support "out-of-the-box" (SD7) thinking. One designer noted: "both I and the user beneficiated a lot from seeing each other's viewpoints and collaborating on the project. I also noticed, the user didn't feel like a subject but rather an active participant" (SD2) and "the source of inspiration" (SU7). Intrinsically, the consensus was a shift towards design with empathy due to greater emphasis on user value judgement to eradicate the "notion that they [students] are star designers as seen in media" (E2) who design for themselves. Therefore, a HCD approach "encourages a bit of empathy" (E2).

Students (designers and users), confirmed an empathetic approach because of created opportunities for designers to "empathise throughout the process making them [user] be part of the entire process" (SD8). Inherently, the 'hero-designer' values metamorphosed to be "more considerate of the user" (SD9) and user value judgements to drive design. Likewise, users disclosed that their designers demonstrated empathy by taking a "closer look at understanding another person" (SU4). Additionally, design with empathy shaped a sense of cognizance for users because they too became "aware that the designer's input counts as much as yours does" (SU3). Consequently, users as core and inspirational source was perceived as "one of the most important principles that runs through the entire process" (SU11) perhaps because pedagogical strategies were designed to accommodate consideration around psychological and sociological issues of designer and user situations to result in co-created value judgements.

8.3.2 Design with Users

Discussion begins with educator perspectives regarding the advantages of design with users to change orthodox teaching practice and students' understanding about passive acceptance which are validated by student views. Deliberations shift to design with users evoking student mind-shifts regarding the role, values, and participation of users to enhance the design process culminating in the call for educators themselves to change. Subsequently, the benefits of design with users illustrate new insights, thinking, inclusivity, collaboration, and shared decision-making.

Educators concurred that design with users is advantageous in changing orthodox teaching practice because "… it's a novel new way of doing things which is going to become much bigger in the future" (E1). The shift in teaching practice created an opportunity to teach students to become future co-constructors, socially and politically responsive designers who understand that they can no longer design products and expect peoples' passive acceptance as confirmed in the quotation: "… we need to just switch our minds out of just designing whatever we want and … expecting people to like what we put out" (E1). Similarly, student responses such as, "because design is with users, I am able to express my interests, likes and dislikes without having to just accept what the designer has designed and made for me" (SU1) confirm educator views.

Intrinsically, educators confirmed that design with users was mind-changing for students as they began to see the role and consideration of user values by incorporating user voice and participation in the design process as commented: "changed their [students] mind on the role that the user can play in the design process and the benefits that come with involving them" (E2). Students who assumed user roles agreed that design with users reshaped their mind-set resulting in a better design approach as reflected in comments: "user and designer became more open-minded" (SU9) and "designing with the user brings about a better approach" (SU5). If such conviction is instilled at an educational level, future designers might well continue to implement design with users and avoid design based on assumptions, personal values and engaged individual design and making activities. However, "we need to just switch our minds" (E1) implies that educators may need an ideological shift regarding relevant ethical and moral choices to guide teaching.

With this educational mind-shift, students learnt to engage with users (albeit students role-playing as users) without assuming that, as designers, they know what people need. Students favoured design with users because they believed that design practice unfolded in a way that better aligns with user needs and values compared with the 'hero-designer' approach. Hence, "this [design] principle is effective, due to the fact that when the user is involved, there is accuracy and proper understanding in what the user wants" (SD5). It can be argued that traditional pedagogy does require students to engage with users and come to understand their needs through market research and statistical analysis. However, as E2 pointed out "… you cannot do that by having a one-hour discussion with them". Innately, design with users aims for depth, inclusivity, and experiences of all those involved which might contribute to value-based appraisal of design in society as opposed to a surface understanding of peoples' needs and values.

For students, design with users brought about new insight with which to design through negotiation and consensus, rather than engaging in a hero-designer-driven approach and thinking. Resultantly, designers and users pooled personal value judgements and design ideas as noted: "it showed me how two minds work better than one. We both have different tastes and values but working together made the design much better" (SU2). Overall, "design with a [the] input from both the user and designer" (SU5) brought about inclusivity by accommodating both voices and promoting collaboration throughout the design process culminating in continuous joint decision-making as confirmed in the statement: "decisions throughout the process, were made with the user" (SD10). Concurringly, one educator (E2) argued that inclusivity, collaboration, and joint decision-making occurred across the design process resulting in informed decision-making. This finding is supported in a comment: "some of them felt that the designer students are going to be taking charge and making all the choices and it was only through exploring the process … that they started realising … the user is also doing things in this case [which] help to make decisions, more better decisions" (E2). Hence, collective designer and user values provide a basis for choice, decision-making and action. Likewise, collaboration also created a sense of awareness about design in that designers "empathise[d] throughout the process making them [user] be part of the entire process" (SD9). This might be because pedagogical strategies did not support students' engagement in individual design and making activities.

8.3.3 Identify User Needs for Integration with Design

Narration commences with the input stage regarding how and why designers engaged in primary research, where information was recorded and how this differed from traditional pedagogical strategies. Thereafter, discussion shows that primary research led to design criteria and constraints but also contributed to social values thus supporting an empathic approach. Consequently, the benefits illustrate student's evoked critical analysis, justification, and opportunity for active learning in co-design. Discussion concludes by showing that primary research for integration with design challenged pedagogical strategies in fashion design education.

To begin *the exploration of the context for designing and making*, the input stage saw designers doing primary research with their respective users to elicit information about their needs, goals, preferences, and context of design usage as reflected in the quotation: "designer was very engaging in conversation with user … started to collect information from user … probed the user to get clarification" (PO). The documentation and synthesis of this primary research in student design journals were well documented with "data [that] was rich" (E2) hence students spent more time directing dialectic engagement with the technical and social dimensions of activity, "rather than sticking pretty pictures in a diary [design journal] … and using ideas from secondary sources" (E2) as pedagogical strategies traditionally required.

Designers and users showed versatility in successfully navigating through primary data collection and synthesis and were able to identify a focussed set of design criteria and constraints regarding user needs, goals, and preferences. Hence, qualitative primary research established the conditions for exploration and understanding to define design criteria without the influence of personal design approach, bias, and value judgements. As one designer commented, "we were able to discern her actual needs and context of use. The main design criteria are not just extracted from hypotheses" (SD7). This contributed to social values of building rapport, developing relationships and consensus in a non-judgemental way as expressed in the comment: "the user was able to communicate with me … without shying away from being judged or questioned" (SD8). These findings lean towards value judgements and sensitivity towards the other person. For this reason, E2 believed that primary research evoked an "an empathic approach in which the designer had to empathise with the user in order to gain a better understanding of what the user required from their product, for example the context of use" (E2).

Identifying user needs, goals and preferences and context of use was "beneficial" (E1) in evoking students' critical analysis and justification of the social consequences involved. The educator could not impose personal values and inclinations because designers were able to justify why they could not digress from their user's needs as echoed: "in class when I made suggestions, let's change this or take this particular direction … they tell me no, the user needs this so we can't really deviate too much from it" (E1). As such, it seems that identifying user needs, goals, and preferences shaped opportunity for student-directed active learning, independent thinking, critical analysis, and justification rather than positioning students as passive recipients of knowledge.

Active learning unfolded with students integrating primary research to trigger co-design activities by exploring diverse ways to engage with design activities, including reflection-in-action by looking back on the initial design criteria to ensure that the design solution addressed the user's needs. Students believed that primary research for integration with design elicited insight about research and how such research informs design practice as echoed: "by doing primary research, I was able to get qualitative information on the user and that formed a strong bases (sic) for our design" (SD10). Accordingly, students were afforded opportunity to "push the boundaries" (SD4) and come up with design solutions that exceeded manifestation of personal values by "making sure that the user is satisfied" (SU6).

Likewise, educators affirmed that designers could not "design what they like" (E1) from inward-looking values because they could not "solely focus on their own preferences and style" (E2). Rather, "in contrast to traditional fashion design projects, … primary data collection allowed for the design of a product that did not focus solely on satisfying the student's own perspective, preferences, tastes and/or style" (E2). The implications are that pedagogical strategies challenged "the past fashion design education which focused on the aesthetic aspects of fashion rather than the functional aspects and the needs of the users. Fashion design has been traditionally driven by the 'vision' and aesthetic of the designer" (E1). However, the shift in pedagogical strategies transformed the ethos, thinking and manifestations of personal values and self-expression to one of co-constructed needs and values to drive co-design activities thus accommodating for negotiations, stakeholder experiences and value-based appraisal.

8.4 The Affordances of the Three Design Principles for Teaching Values in Technology Education

It has already been mentioned and acknowledged in the literature on technology and technology education that technology is value laden. Parts of the theoretical framework that underpins this section have been published elsewhere in a different format like the implications of Andrew Feenberg's critical theory of technology for the teaching of values in technology education (Ankiewicz, 2019). Technology exists because of human activity and is developed and used in social and environmental contexts. As such, it is shaped by communal beliefs, values, and attitudes of individuals, organisations and society and, in turn, has a significant effect on shaping culture and the environment (Conway, 1994; Martin, 2002; Stables, 2017). Technology education based on determinism and instrumentalism that views technology as value neutral will reduce technology education to technical education (Conway & Riggs, 1994; Hansen, 1997; Martin, 2002; Stables, 2017). The distinct types of values in technology education will be discussed in the next section.

8.4.1 Types of Values in Technology Education

A meta-synthesis of literature reveals various values in technology and in technology education, for example aesthetic, economic, social, moral, environmental, political, and spiritual values (Jones et al., 2013; Martin, 2002; Pavlova, 2005). Scholars have classified these values into broader categories.

Values of function (Rekus, 1991) and formal, practical, and technical values (Pavlova, 2005) are synonymous and referred to as technical values, which relate to value judgements concerning the functionality/efficiency and effectiveness of technology. Technical values are strongly dominating in most approaches in technology education, but without explicitly referring to them as values (Pavlova, 2005). Teachers (to represent educators at school level) put the highest priority on teaching technical values (Holdsworth & Conway, 1999; Pavlova, 2005), with their hierarchy of values resembling the following: technical, aesthetical, economic, environmental, social, cultural, moral, and political (Pavlova, 2005).

A second type of values is instrumental values (values of usage) (Rekus, 1991) or non-technical values (Pavlova, 2005). Values of usage are judgments concerning the morality of action related to the usage of technology, which may only be done by acting individuals themselves (Rekus, 1991). Instrumental values encompass such concepts as ambitious, open-minded, capable, helpful, honest, imaginative, intellectual, logical, responsible, and self-controlled (Pavlova, 2005). Technology education mostly deals with two major kinds of instrumental values, namely those with a moral focus and those related to competence or self-actualisation. In the practice of technology education, values related to competence take priority over moral values (Holdsworth & Conway, 1999; Pavlova, 2005). Pavlova (2005) argues that moral values should take priority in the hierarchy.

Moral education will be emphasised if technology education includes technical (formal, practical or values of function) and non-technical values (instrumental or values of usage) (Rekus, 1991). Teachers need to introduce students to the kinds of moral dilemmas they will face in everyday life as a direct result of the spread of technology (Dakers, 2005).

In the next section the authors argue that emphasising the above-mentioned three design principles might be instrumental to create a shift from the dominance of technical values, as well as values related to competence, to moral values in technology education. The three design principles will be linked to the theoretical framework for values in technology education, and the linkages will be indicated by showing the relevant design principles in brackets.

8.4.2 Teaching Values in Technology Education

As moral values are inherently part of acting individuals themselves (Rekus, 1991), the most frequently proposed way of teaching values in technology education is to encourage students to think about values themselves (DP3) (Pavlova, 2005). Technology teachers and students need to be explicit about the values involved at all levels of technology and to clarify, justify and debate their choices (Conway, 1994; Conway & Riggs, 1994; McLaren, 1997; Riggs & Conway, 1991). Technology teachers should be upfront about the collective values guiding technological development in society and in technology education, as well as the specific values which guide both technologists and prospective technologists in schools (Riggs & Conway, 1991). Students should have opportunities of valuing technology independently without teachers imposing their own sets of values and norms (DP3) (Rekus, 1991).

Within Martin's (2002) stage of *exploring the context for designing and making*, the choice of the starting point of a technology project is important to show the connections between context, technology, and value judgments (DP1) (Conway & Riggs, 1994; Martin, 2002). The teacher should choose an issue or project brief that relates to the current value system of the students (DP3), taking psychological and sociological aspects of the students' situation into consideration (DP1, 3) (Rekus, 1991). In this regard, technology teachers may capitalise on the pedagogies associated with science, technology, and society (STS) studies. STS studies may promote a critical approach to technology in curriculum documents by considering the relationship between society and technology (Pavlova, 2005). STS teaching commences with everyday issues instead of organising technology lessons around concepts and processes (DP1, 3). Furthermore, interdisciplinary project work and integrated STS programmes may create a context in which students construct their relationship with technology and learn about its topical, motivational, and interpretative meaning (DP2, 3) (Hansen, 1997). It may also require some integration across artificial subject boundaries of the school curriculum (DP2) (McLaren, 1997). It is important for technology teachers to encourage critical thinking and questioning so that students are aware that technology is related to people, society, and the environment (DP3). How students' value technology will shape their future (DP3) and they are entitled to discuss such issues in the classroom (DP1) (Jones et al., 2013; Martin, 2002).

Dakers (2005) cautions, that because of the so-called narrow functionalist model, many technology students, when faced with a problem, attempt to proceed directly from problem statement to solution. Students are consequently unable to engage with the social and political ramifications provoked by the spread of new and emerging technologies (DP2, 3). Learning in this model aims at the assimilation of students into an already established value system which is more concerned with control than with liberation. Based on the instrumental role of technology and its social and cultural implications, Dakers (2005) argues for a new pedagogy for technology education that engages students with questions concerning technology (DP1, 2). The current authoritarian transmission model of instruction should be replaced by one in which values relating to technology and technology education are co-constructed rather than imposed (DP1, 2, 3).

One of the best ways of assessing the impact of values or moral education is to look at the way in which students' design processes are informed by applying value judgements and a sensitivity towards users (DP1, 2, 3) (Martin, 2002). It is therefore crucial that students are given the opportunity to reflect on their explorations of a value-based appraisal of technology in society (DP2, 3) allowing their reflections to influence their own approach to design (DP3) (McLaren, 1997). Students should be accorded opportunities to not only act as 'hero-designers' following the narrow behavioural approach (Dakers, 2005), but also to negotiate and collaborate with users (DP2, 3). They should be exposed to knowledge in technical disciplines which is associated with 'hero-designers' as well as qualitative knowledge associated with users (DP3).

An overemphasis on teaching technical values and values related to competence (Holdsworth & Conway, 1999; Pavlova, 2005) at the expense of moral values reduces technology education to technical education. Students need to look beyond immediate usefulness and profitability to effects on users (DP2, 3), through environmental impact (Riggs & Conway, 1991). By attending to the context and the experience of all those involved (DP1, 2, 3), the range of values may be made explicit and confidence in handling value judgments may be encouraged (Conway, 1994). According to Dakers (2005) a narrow functionalist model of learning and teaching within the technology education curriculum is more concerned with the processes embedded within the methods of a technology's production and manipulation, than with a critical analysis of the social consequences involved (DP2, 3).

These include a shift from teaching content matter in isolation from social considerations, towards a dialectic engagement with the technical and social dimensions of technological activity (DP2, 3), to make technology education meaningful to all students (Hansen, 1997; Rekus, 1991). Students also need to examine relevant ethical and moral choices as well as factors that enable or influence critical design decisions (DP2, 3) (McLaren, 1997). Without such an ideological shift, technology education will remain a narrow and limited curricular area, restricted to the production of a technologically subservient and compliant underclass (Dakers, 2005). The design or technological process furthermore involves a great deal of decision-making. Choices are made before every stage, for instance choosing what to make (Martin, 2002). Values provide a basis for choice, decision-making and action in a wider context (DP2, 3) (Pavlova, 2005).

Students should know that technological development depends on values on the one hand and has its own laws of development on the other hand (Pavlova, 2005). Subsequently, and as part of a critical and democratic pedagogy within technology education (Dakers, 2005), students should also be introduced to the politics of technology that is essential for a technical democracy (DP2, 3). Students' ability to make value judgements will not only enable them to handle present technology, but also empower them to cope with future ethical demands of a rationally structured society when they must make responsible political decisions as citizens or politicians (Rekus, 1991). Students should also be sensitised to how the public's resistance based on a broad range of politically legitimated human values may give rise to alternative rationalities (DP2, 3). This opens the opportunity to develop technology beyond the technical values of economics and effectiveness only (Pavlova, 2005). Drawing from these linkages between values in technology education and the design principles, the subsequent section concludes with pragmatic guidelines for co-design pedagogy to teach moral values in technology education.

8.5 Conclusion

It is accepted that technology and technology education are value laden. Thus, technology education should create opportunities for students to learn about and practically apply value judgements to enable them to become future agents of change. However, in the practice of technology education, technical values and values related to competence take priority over moral values. Pavlova (2005) argues that moral values should take priority in the hierarchy, while Dakers (2005) calls for a new pedagogy in which values relating to technology and technology education are co-constructed rather than imposed.

Hence, the proposed co-design (an approach to HCD) as a new pedagogy for university fashion design education. The scholarship of HCD was first reviewed to define design principles of HCD. Although several design principles emerged, three were considered for this chapter namely: (1) users as core and inspirational source (DP1), (2) design with users (DP2), and (3) identify user needs for integration with design (DP3). These three design principles of HCD specifically linked to Martin's (2002) stage: *the exploration of the context for designing and making* and were used to design two teaching and learning interventions.

Following from the findings which emanated from the qualitative design-based research in fashion design education, and congruent to Dakers' (2005) call, we believe that a pedagogy based on the three design principles might be conducive to affect a shift from the dominance of technical values and competence as non-technical values to moral values. Thus, based upon our meta-synthesis of the theoretical framework of values in technology education and its link with the findings of the three design principles we propose new pedagogy for co-design to teach moral values in technology education that comprises the following: When introducing a technology project to students for the stage of *exploring the context for designing and making* divide them in pairs of two where the one assumes the role of designer and the other one the role of user. The technology teacher must ensure that the curriculum, learning outcomes and activities are planned to accommodate for: (1) users to be the core and inspirational driver, (2) for students to engage in primary qualitative research with users to explore their views and values for integration with design, (3) create opportunities for co-design activities and (4) place less emphasis on the functionality/efficiency and effectiveness of students' products. Likewise, teachers should change their ideological beliefs, imposition of personal value judgements and pedagogical strategies to accommodate for student engagement, co-constructed values, and collaboration.

This proposed new co-design pedagogy should be further explored at school level through action research cycles as further research in future. As mentioned earlier, in this research, role-playing in design teams comprised of two members with agency to select respective roles. However, as a way forward, action research could be that teachers' grant student's agency to role-play in a two-member design team or even a three-member design team with one user and two designers, or vice versa. The question remains, how will teachers implement this role-playing in an effective way that two or even three students with same aptitudes role-play as designers and users? Likewise, through action research, it becomes questionable how teachers can set up the role-playing in a way where the user and designer are both knowledgeable in what they are supposed to do.

References

Amiel, T., & Reeves, T. C. (2008). Design-based research and educational technology: Rethinking technology and the research agenda. *Educational Technology & Society, 11*(4), 29–40.

Ankiewicz, P. (2019). The implications of Feenberg's critical theory for technology education. In J. R. Dakers, J. Hallström, & M. J. de Vries (Eds.), *Reflections on technology for educational practitioners: Philosophers of technology inspiring technology education*. Brill/Sense.

Baynes, K. (2010). *Models of change: The impact of 'designerly thinking' on people's lives and the environment*. *Seminar 4 modelling and society*. Design: Occasional paper 6. Loughborough University. https://repository.lboro.ac.uk/articles/Models_of_change_the_impact_of_designerly_thinking_on_people_s_lives_and_the_environment_seminar_4_modelling_and_society/9350111

Barlex, D. (1993). The Nuffield approach to values in design and technology. *Design and Technology Teaching, 26*(1), 42–45.

Breckon, A. (1998). National curriculum review in design and technology for the year 2000. *The Journal of Design and Technology Education, 3*(2), 101–105.

Conway, R. (1994). Values in technology education. *International Journal of Technology and Design Education, 4*(1), 109–116.

Conway, R., & Riggs, A. (1994). Valuing in technology education. In F. Banks (Ed.), *Teaching technology*. Routledge.

Collins, A., Joseph, D., & Bielaczye, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the Learning Sciences, 13*(1), 15–42.

Dakers, J. R. (2005). The hegemonic behaviorist cycle. *International Journal of Technology and Design Education, 15*(2), 111–126.

Hansen, K. H. (1997). Science and technology as social relations towards a philosophy of technology for liberal education. *International Journal of Technology and Design Education, 7*(1–2), 49–63.

Harvey, R. N. (2018). *A Human-centered design approach to fashion design education* (Doctoral thesis). University of Johannesburg. https://ujcontent.uj.ac.za/vital/access/manager/Repository/uj:32308?site_name=GlobalView

Harvey, N. Ankiewicz, P., & Van As, F. (2019a). Fashion design education: Effects of users as design core and inspirational source. In *Conference Proceedings of the 37th International Pupils' Attitudes Towards Technology (PATT) Conference held in Malta.* Conducted by the L-Università ta' Malta.

Harvey, N. Ankiewicz, P., & Van As, F. (2019b). Design-based research: Bridging the gap between fashion design education and research on design. In *Conference Proceedings of the 8th International Design Education Forum of Southern Africa (DEFSA) Conference held in Cape Town.* Conducted by IIE Vega School and Cape Peninsula University of Technology.

Holdsworth, I., & Conway, B. (1999). Investigating values in secondary design and technology education. *The Journal of Design and Technology Education, 4*(3), 205–214.

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.

Layton, D. (1991). *Aspects of national curriculum: Design & technology*. National Curriculum Council.

Martin, M. (2002). Values and attitudes in design and technology. In S. Sayers, J. Morley, & B. Barnes B. (Eds.), *Issues in design and technology teaching*. Routledge Falmer.

McLaren, S. V. (1997). Value judgements: Evaluating design—A Scottish perspective on a global issue. *International Journal of Technology and Design Education, 7*(3), 259–278.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation.* Jossey-Bass.

Middleton, H. (2005). Creative thinking, values and design and technology education. *International Journal of Technology and Design Education, 15*(1), 61–71.

Ordaz, M. N., Klapwijk, R., & van Dijk, G. (2018). Supporting learning design language in primary education. In *Conference Proceedings of the 36th International Pupils' Attitudes Towards Technology (PATT) Conference held in Malta.* Conducted by the Athlone Institute of Technology, Co. Westmeath.

Pavlova, M. (2005). Knowledge and values in technology education. *International Journal of Technology and Design Education, 15*(2), 127–147.

Plomp, T. (2010). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *An Introduction to Educational Design Research. Seminar Proceedings Conducted at the East China Normal University, Shanghai (PR China).* Netherlands Institute for Curriculum Development: SLO.

Prime, G. M. (1993). Values in technology: Approaches to learning. *Design and Technology Teaching, 26*(1), 30–36.

Reeves, T. (2006). Design research from a technology perspective. In J. V. D. Akker, S. Gravemeijer, S. McKenny, & N. Nieveen (Eds.), *Educational design research.* Routledge.

Rekus, J. (1991). Teaching technology with a focus on moral education. *International Journal of Technology and Design Education, 2*(2), 41–46.

Riggs, A., & Conway, R. (1991). Values and technology education. *Design & Technology Teaching, 24*(1), 31–33.

Sanders, E. B. N., & Stappers, P. J. (2012). *Convivial toolbox: Generative research for the front end of design.* BIS Publishers.

Saldaña, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). Sage.

Stables, K. (2017). Critiquing design: Perspectives and world views on design and design and technology education, for the common good. In P. J. Williams & K. Stables (Eds.) *Critique in design and technology education. Contemporary issues in technology education.* Springer.

Steen, M. (2011). Tensions in human-centred design. *CoDesign, 7*(1), 45–60.

Neshane Harvey is Head of Department and Associate Professor in the Department of Fashion Design, Faculty of Art, Design and Architecture at the University of Johannesburg. She has dual qualification streams in fashion design and education specializing in design education. Her research interest is on human-centered design (co-design/participatory design) praxis as alternative pedagogy for fashion design education. She is a member of the Design Education Form of Southern Africa (DEFSA).

Piet Ankiewicz is full Professor of Technology Education in the Faculty of Education at the University of Johannesburg. His research interests include the affordances of the philosophy of technology for technology classroom pedagogy, teacher education, indigenous technology knowledge systems, and STEM education. He also has an interest in students' attitudes towards technology. He has been rated by the National Research Foundation as an established researcher with international recognition. He is a member of the Editorial Board of the *International Journal of Technology and Design Educatio*n.

Chapter 9
Using Engineering Design in Technology Education

Euisuk Sung and Todd R. Kelley

Abstract In contemporary technology education, engineering design is becoming an essential component to connect technology with Science, Mathematics, and Engineering. The engineering design process is an iterative process of devising a system, component, or strategy to meet desired needs. Still, there are many unanswered questions: "Why do we use the engineering design process?" "How do we use the design process?" and "How do students use the engineering design process to solve technological problems?" This chapter will review the existing engineering design process models presented by textbooks and researchers. Then, the author considers contemporary learning theories that align with the engineering design process in terms of design cognition. Next, the author will present a design process model derived from an experimental pattern study. This chapter will explain how students perceive and undertake the engineering design process in an authentic problem-solving setting, based on the research findings. Finally, this chapter contains practical suggestions on the use of the engineering design process in the classroom.

Keywords Engineering design · Sequential analysis · Engineering and technology education · STEM education · Design cognition

9.1 The Questions I Asked and Why They Are Important

With the integrative movement of Science, Technology, Engineering, and Mathematics (STEM) education, engineering design is positioned as an essential component of technology and engineering education. The International Technology and Engineering Educators' Association (ITEEA) released the new standards, named Standards for Technological and Engineering Literacy (STEL; ITEEA, 2020), which

E. Sung (✉)
New York City College of Technology, New York, USA
e-mail: ESung@citytech.cuny.edu

T. R. Kelley
Purdue University, West Lafayette, USA

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_9

include engineering literacy as one of the core components of technology education. STEL described engineering as using scientific principles and mathematical reasoning to optimize technologies to meet needs defined by criteria under given constraints. The adoption of engineering in technology education can be considered in terms of two functions of engineering: (1) as noun engineering means a discipline, artifacts, and careers; (2) as verb engineering refers to engineering actions such as designing, developing, researching, and applying of engineering habits of mind. In technology education, the two aspects have been implemented through the engineering design process. The Standards for Technological Literacy (STL; ITEEA, 2000/2003/2007) stated that "Engineers […] use a particular approach called the engineering design process. […] The engineering design process demands critical thinking, the application of technical knowledge, creativity, and an appreciation of the effects of design on society and the environment" (p. 99). The use of engineering design helps students develop the engineering habits of mind and consider engineering a possible future career.

However, little is known about the engineering design process, particularly for K-12 education. Many technologies and engineering textbooks introduce engineering design as a technological problem-solving process and present numerous design process models. Still, little emphasis is given to how educators and students use the process models. One of the most prevalent misconceptions about the engineering design process is the belief that it provides an optimal problem-solving process. Mosborg et al. (2005) studied the authenticity of engineering design processes where the researchers asked engineers how their practices compare to a design process model shown in technology and engineering textbooks. Their study revealed that most engineering practitioners disagreed with the design process model because the actual engineering design process contains complex iterations that vary depending on the types of problems and contexts. Another misconception about the engineering design process is that it is a linear or single path. The volume of design studies confirmed that there is no single correct procedural pathway of the design process (Chan & Schunn, 2015; Dorst & Cross, 2001; Jin & Chusilp, 2006; Kim & Kim, 2015). Instead, the researchers agreed that design processes are highly iterative and vary in type, context, designer expertise, and other factors (Adams, 2002; Dorst, 2004; Harfield, 2007; Jonassen, 2000; Kruger & Cross, 2006). Therefore, in this study, the author attempted to identify how students perform design tasks focusing on the engineering design process resulting in two research questions.

1. What are the characteristics of the engineering design process of elementary students when solving engineering challenges?
2. What are the patterns of the problem-solving strategies in the engineering design process?

9.2 How I Answered the Questions

The context of this study was the National Science Foundation (NSF)-funded Math Science Targeted Partnership (MSP) Science Learning through Engineering Design (SLED). The project was conducted for five academic years, from 2011 to 2016. The SLED project built collaborative partnerships with four colleges within a large, research-intensive university and four school corporations located in the Midwest of the USA. The project's overarching goal was to enhance science learning by integrating the engineering design approach into the elementary classroom. Throughout the five-year project, the research project videotaped 48 engineering design team challenges, and each team consisted of three elementary students. The total number of participants was 144, and the entire duration of video and audio recording was 13 h 52 min. The SLED research team developed the engineering design challenges used in this study. This project used eight engineering design challenges, as listed in Table 9.1.

This study adopted a sequential analysis method to detect the patterns of the design process in engineering challenges (Bakeman & Gottman, 1986). The author observed students' behaviors when the elementary students responded to the engineering design challenges and found repeating patterns of design strategies. For example, students often start an engineering challenge with identifying problems and then move to the analysis process, where they research the constraints and criteria of the challenge. Also, when generating design solutions, they tended to move back and forth between questioning, predicting, and drawing stages of the engineering design process. The underlying idea of this study was the repeated design strategies form clusters of design patterns, and the collection of the clustered patterns characterize the design behaviors. The author believed that identifying patterns not only helps identify how students perform the engineering design but also provides a fundamental understanding of how students solve engineering problems. Therefore, this study sought the statistical significance of repeating design behaviors using a pattern detection methodology presented by Bakeman and Gottman (1986). The adoption of

Table 9.1 Engineering design challenges

Grade	Lesson title	Engineering and science concepts
Grade 3	Musical instrument	Sound, pitch, waves
	Simple machine	Force, gears, lever, pulley, wedge, fulcrum
Grade 4	Canal	Erosion, drainage, slope, runoff
	Door alarm	Electrical power, open- and closed-circuits, load
Grade 5	Prosthetic leg	Mass, volume, kinetic energy
	Water filter	Filtration, purification, water quality
Grade 6	Roller coaster	Potential energy, kinetic energy, gravity, friction
	Solar tracker	Earth rotation, direct versus indirect lights, ball bearings, linkage

Table 9.2 Engineering strategy coding scheme

Design strategy (Code)	Description
Defining problem (s) (DF)	stating or defining a problem which will enhance the investigation leading to an optimal solution
Analyzing (AN)	identifying, isolating, or breaking down to clarify the essential components of the problem
Predicting (PR)	prophesying or foretelling something in advance; anticipating the future based on special knowledge
Questions (QH)	asking, interrogating, challenging, or seeking answers related to a problem
Designing (DE)	conceiving, creating, inventing, contriving, or planning
Managing (MA)	planning, organizing, directing, coordinating, and controlling the inputs and outputs of the system
Modeling (MO)	presenting ideas graphically in the form of a sketch, diagram, or equation

the pattern detection technique allowed the researcher to present the results through statistical significance.

This study used the Concurrent Think-Aloud (CTA) protocol, a research method that asks the participants to speak aloud while performing specific tasks. The research team videotaped the participants' design strategies and coded them using Halfin's (1973) codes. Halfin developed 17 cognitive strategies commonly used by engineers and scientists in his dissertation study. This study revised his codes and adopted seven of the initial codes, as shown in Table 9.2.

9.3 What I Found Out

To characterize the process of problem-solving in engineering design, the author presents the pattern analysis results using average time percentages, the frequency, and the duration of design strategies used in the 48 CTA sessions. Based on the coding results, the author conducted a sequential pattern analysis to detect the cognitive patterns of the design process. The coded raw data were exported to a string of sequential events and analyzed using GSEQ software (Bakeman & Quera, 2015).

9.3.1 Use of the Engineering Design Process

To identify the features of design strategies used by elementary students in engineering design challenges, the author analyzed the 48 engineering design sessions. Table 9.3 and Fig. 9.1 illustrate how elementary students utilized design strategies

Table 9.3 Time usages in 48 engineering design sessions

Design strategy	Mean	SD	Min	Median	Max
Analyzing (AN)	01:09.7	01:04.2	00:00.0	01:01.4	05:05.2
Designing (DE)	08:01.4	03:13.6	00:39.5	08:26.0	14:18.2
Defining Problems (DF)	02:03.3	00:31.4	01:07.3	01:53.1	03:19.8
Managing (MA)	00:50.5	00:38.4	00:00.0	00:49.6	02:21.8
Modeling (MO)	03:15.9	01:52.2	00:15.6	03:16.9	06:49.3
Predicting (PR)	01:05.2	00:44.2	00:00.0	01:08.3	03:38.7
Questioning (QH)	00:54.1	00:43.0	00:01.1	00:40.5	02:56.2
Total	17:20.2				

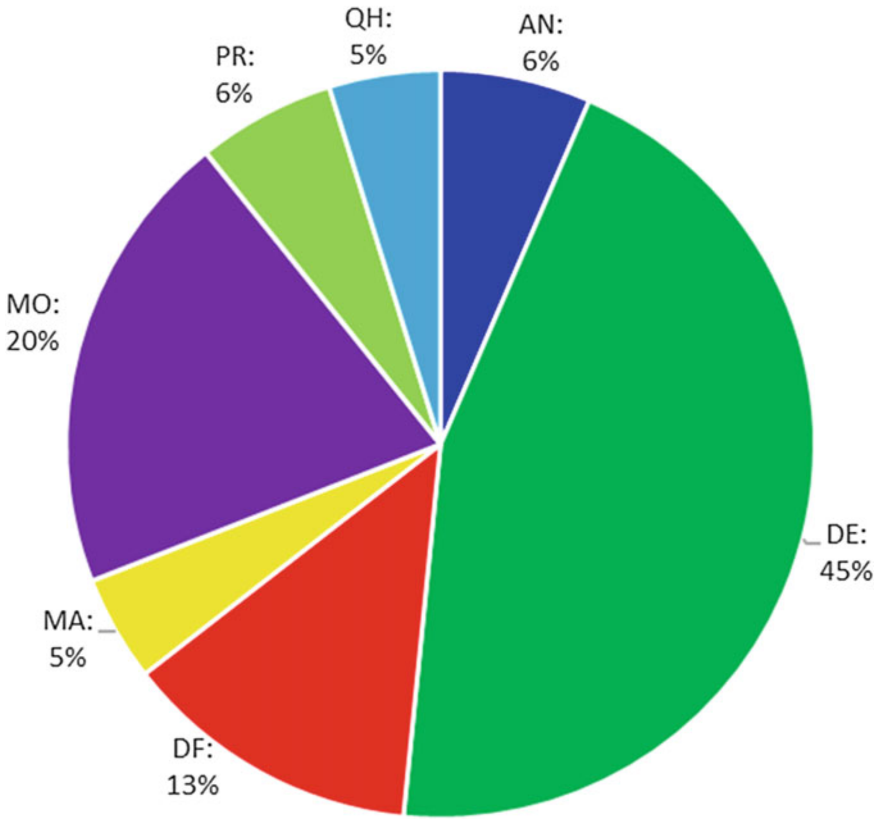

Fig. 9.1 Mean time percentages of 48 CTA sessions

with their time usages. The average duration of the engineering design session was 17:20.2 (17 min and 20.2 s). The shortest session was 5:35.4, and the most extended session was 28.03.6 min. The overall statistics indicate that the participants spent most of their time Designing (DE, duration (d) = 08:01.4) and minoring in Managing (MA, d = 00:50.5), Predicting (PR, d = 01:05.2), or Analyzing (AN, d = 01:09.7).

The author presented the time usages in each design challenge to understand how the different design challenges shape other design behaviors. Because each engineering design challenge had different time lengths, the researcher converted the measured time into the relative duration per 10-min interval.

The results show that almost half of the time in the engineering challenges was dedicated to Designing while Predicting, Questioning, Managing, and Analyzing were relatively small. For example, the individual charts in Fig. 9.2 indicate that students spent longer in Designing in the Simple Machine challenge, which required designing a physical device to save a wolf from a trap. Also, students spent more time Analyzing design strategies in the Water Filter and Canal design challenges which had longer design statements with complex design requirements.

9.3.2 Common Design Patterns of the Engineering Design Process

This study conducted a sequential pattern analysis to identify the patterns of the sequential process of the engineering design strategies. The pattern analysis relies on the sequential order of design strategies and their frequencies. Table 9.4 shows the overall statistics of design strategy frequencies with their sequences. For example, the number 198 (212.52) in the cell crossing AN and DE implies the transitions from Analyzing to Designing occurred 198 times. Accordingly, the expected frequency of 212.52 indicates that the expected statistical number of shifts from Analyzing to Designing was 212.52 based on the AN row (355) and DE column (1,939).

Based on the numbers of observed and expected statistics, the author obtained statistical possibilities of the sequential transitions with z-scores and p-values shown in Table 9.5. For example, the p-value crossing AN and MA was 0.047 ($z = 1.99$), which implies the transitions from Analyzing to Managing were statistically significant compared to other sequential events. The bold values in Table 9.5 indicate the patterns statistically significant at the 0.05 level.

The author visualized the results in Table 9.5 by illustrating statistically significant transitions with their sequential orders in Fig. 9.3. Figure 9.3 reflects that most of the engineering design sessions started with reading the design brief, so the patterns begin with Defining Problems (DF, $n = 167$). There exist two pathways from Defining Problems to the next stages of Analyzing (DF → AN, $p < 0.001$, $z = 16.02$) and Managing (DF → MA, $p < 0.001$, $z = 6.81$). The Analyzing (AN, $n = 355$) stage had two significant paths to Questioning (AN → QH, $p = 0.007$, $z = 2.72$) and Managing (AN → MA, $p = 0.047$, $z = 1.99$). Questioning (QH, $n = 636$) also had

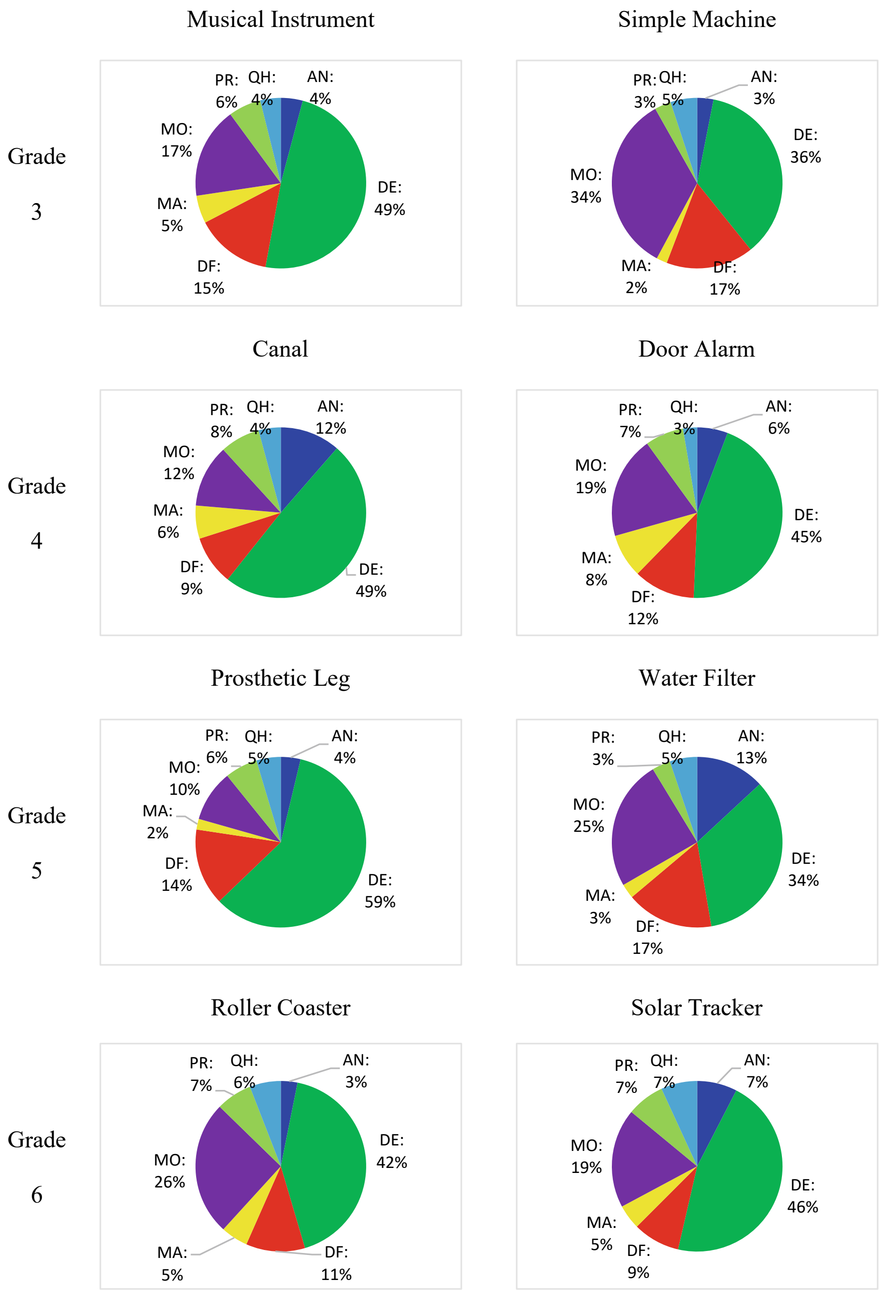

Fig. 9.2 Mean percentages of design strategies by engineering design challenges

Table 9.4 Observed and expected frequencies of design strategies in 48 engineering design sessions

Observed (Expected)	Given								
		AN	DE	DF	MA	MO	PR	QH	Total
Target	AN		198 (212.52)	24 (05.75)	33 (24.04)	34 (56.08)	19 (23.65)	47 (32.96)	355
	DE	152 (212.01)		52 (69.20)	209 (289.52)	805 (675.42)	367 (284.87)	343 (397.00)	1,928
	DF	51 (08.01)	68 (96.75)		32 (10.94)	7 (25.53)	0 (10.77)	9 (15.01)	167
	MA	36 (22.57)	250 (272.54)	23 (07.37)		86 (71.92)	9 (30.33)	43 (42.27)	447
	MO	36 (55.89)	646 (674.79)	11 (18.24)	127 (76.32)		42 (75.10)	143 (104.66)	1,005
	PR	18 (23.56)	293 (284.42)	1 (07.69)	57 (32.17)	47 (75.05)		51 (44.11)	467
	QH	62 (32.96)	484 (397.97)	8 (10.76)	20 (45.01)	30 (105.01)	32 (44.29)		636
	Total	355	1,939	119	478	1,009	469	636	5,005

Table 9.5 z-scores and p-values of sequential design strategies

P-value (Z-score)	Given							
		AN	DE	DF	MA	MO	PR	QH
Target	AN		0.187 (−1.32)	**<0.001**[a] **(8)**	**0.047**[a] **(1.99)**	0.001 (−3.42)	0.298 (−1.04)	**0.007**[a] **(2.72)**
	DE	<0.001 (−5.45)		0.008 (−2.67)	<0.001 (−6.35)	**<0.001**[a] **(7.12)**	**<0.001**[a] **(6.52)**	<0.001 (−3.7)
	DF	**<0.001**[a] **(16.02)**	<0.001 (−3.8)		**<0.001**[a] **(6.81)**	<0.001 (−4.17)	<0.001 (−3.51)	0.091 (−1.69)
	MA	**0.002**[a] **(3.07)**	0.067 (−1.83)	**<0.001**[a] **(6.11)**		0.051 (1.95)	<0.001 (−4.26)	0.897 (0.13)
	MO	0.002 (−3.09)	0.114 (−1.58)	0.055 (−1.92)	**<0.001**[a] **(6.82)**		<0.001 (−4.49)	**<0.001**[a] **(4.49)**
	PR	0.211 (−1.25)	0.497 (0.68)	<0.010 (−2.56)	**<0.001**[a] **(4.83)**	<0.001 (−3.81)		0.242 (1.17)
	QH	**<0.001**[a] **(5.62)**	**<0.001**[a] **(5.9)**	0.363 (−0.91)	<0.001 (−4.2)	<0.001 (−8.77)	0.038 (−2.08)	

Note [a] Right-tailed at 0.05 level

two significant sequential patterns to Analyzing (QH → AN, $p < 0.001$, $z = 5.62$) and Designing (QH → DE, $p < 0.001$, $z = 5.9$). The Designing (DE, $n = 1{,}928$) strategy resulted in two significant transitions to Predicting (DE → PR, $p < 0.001$, $z = 6.52$) and Modeling (DE → MO, $p < 0.001$, $z = 7.12$).

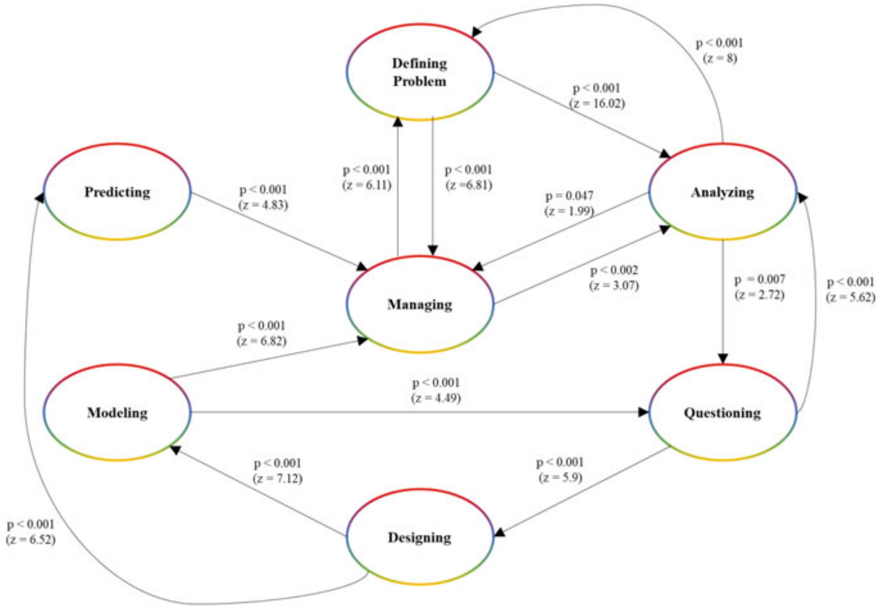

Fig. 9.3 Pattern diagram of design strategies with statistical significance

The model shows the recursive patterns of all design stages. There exist bidirectional patterns between Defining Problems and Analyzing, Analyzing and Questioning, Analyzing and Managing, and Defining Problems and Managing. The researcher also found cyclical patterns between Questioning, Designing, Predicting, Modeling, and Managing. After Questioning, the model shows two subsequent design pathways: (1) Questioning → Designing → Modeling → Questioning or Managing, and (2) Questioning → Designing → Predicting → Managing. These results indicate that the Designing (DE) strategy relates to Modeling and Predicting, which externalizes mental representation by drawings (MO) or predicts the consequences of design ideas (PR). Another finding from the pattern diagram is that Managing (MA) was a mediator of Design strategies. The Managing was associated with problem identification strategies (MA ↔ DF, MA ↔ AN) and solution strategies (MO → MA, PR → MA). The Managing coding scheme contained control assertions such as "What's next?" "What would we do?" "Let's do this." Using Managing cognition, the participants iterated their design strategies from solution strategies to problem strategies.

9.4 How Can This Research Be Used to Improve Teaching and Learning?

9.4.1 Concentration on Designing and Modeling

The results identified that the participant students spent more than half of their time in *Designing (45%)* and *Modeling* (20%). The high percentage of the two design strategies illustrates that vital engineering design elements are generating solutions and expressing ideas to share, implement, and test the solution. There is no clear evidence that the high percentages of design and modeling represent a good design strategy. However, Atman and her colleagues (2007) found that engineering experts tend to spend more time designing than novices. Mentzer et al. (2015) compared the use of problem-solving strategies between high school and college students and concluded that college students are prone to spend more time on solution strategies (designing, modeling, and predicting) while high school students tend to focus on problem strategies (problem identification and analyzing). In summarizing the findings of this study and literature research, *Designing* and *Modeling* are the heart of engineering design, and expert engineers tend to focus on these stages more than other strategies. While there is no guarantee staying in Designing and Modeling longer produces a quality design, this result may imply that technology and engineering educators will need to provide appropriate and effective strategies to identify the design problem and focus on ideations, modeling, and designing.

9.4.2 Use of Modeling as a Mental Tool

The use of modeling strategies in engineering design prompts a rethink of the engineering design process in terms of design cognition. Goldschmidt (1991) noted that engineers use sketching as a tool to display mental images, which informs us that students similarly need to learn the way to visualize their mental ideas as a form of realization (Goldschmidt, 1991). Sung et al. (2019) showed that the use of informed sketching techniques with schematic symbols and strategic approaches led to quality design sketches and creative ideas. In this study, the research found *Designing* and *Modeling* occurred sequentially after *Questioning* strategies. For example, many triad design teams started designing with guiding questions such as “how can we improve this solution?” and then generated ideas and stored them as a form of sketching. Cognitive scientists argued that the mental capacity of a human is limited to holding a certain amount of information so that it can process only a few pieces of information at a time, and only a few are transferred to long-term memory (Bruning et al., 2011). However, this study indicates that engineering design helps students expand their mental capacity through sketching, an externalized device for modeling mental images. This result implies a critical point that engineering and technology educators should not overlook the power of sketching in engineering design, including rough freehand sketching.

9.4.3 Problem Versus Solution-Oriented Approaches

This study confirmed that the participants emphasized problem identification more diminutive than the other design strategies. The mean percentages of Defining Problem and Analyzing were 13% and 6%, respectively. This study showed that the use of Defining Problems and Analyzing varied by design task. The percentages of Defining Problem ranged from 9% of Solar Tracker to 17% of Simple Machine. The rates of Analyzing varied from 3% of Simple Machine to 13% of Water Filter. The results show that the participants heavily focused on problem identification (see Fig. 9.2). Several design studies have investigated the relationship between problem identification and the quality of the design. Atman and Bursic (1998) investigated the relationship between the ratio of problem-scoping and solution quality. They confirmed that more emphasis on problem-scoping yielded a quality design solution. Kruger and Cross (2006) compared the outcomes of problem-driven and solution-driven designs. Their study demonstrated that the design strategies focused problem-driven resulted in low creativity scores and high overall design quality. Meanwhile, solution-driven strategies yielded high creativity and lacking overall quality. Although there is no clear evidence which approach is dominantly excellent or bad, technology and engineering educators need to consider a balanced problem- and solution-driven design strategies depending on students' prior knowledge and skills in engineering design.

9.4.4 Stressing the Iterative Design Process

Most design process models illustrate the engineering design process as a sequential procedure. For example, one of the well-known design process models, French's design process model (1999), depicted design process as a sequential process of (1) Identifying the need, (2) Analysis of problem, (3) Statement of the problem, (4) Conceptual design, (5) Selected schemas, (6) Embodiment of schemas, (7) Detailing, and (8) Working drawings. While this model stresses the recursive nature of the design process, many students and teachers misunderstand by thinking that the design process is a strict procedure that they should follow to achieve the best results (Crismond & Adams, 2012; Mosborg et al., 2005). Koen (2003) noted that engineers want to produce the best solution to their problems. The notion of the best solution is often called *optimization* in engineering. However, authentic engineering design problems do not have the best solution to all problem types. A design process model is a shortcut to a solution that meets the design criteria under certain constraints, not an approach to reach the best solution. As shown in the pattern-based design process model in Fig. 9.3, the author confirmed multiple pathways in the engineering design process. Nowadays, many engineering problems require creative and innovative solutions. However, fixed, and inflexible design processes yield uniform design solutions and do not offer creative solutions. The findings of this study confirmed that students did not follow a fixed design pathway. Instead, they tended to iterate several design strategies to explore solutions to the problem. This may imply that educators need to avoid forcing students to follow a fixed design process and encourage them to iterate design steps to find better solutions.

9.4.5 Engineering Inquiry

Burks (1946) defined inquiry as an activity of resolving authentic doubt to achieve a stable belief. Crismond and Adams (2012) noted that informed designers use inquiry to collect, organize, and analyze evidence that provides rich resources for engineering design devices and systems. Engineers' inquiry is comparable with scientific inquiry. Junginger (2007) argued, "to arrive at good design today, designers have to get involved in a systematic inquiry beyond aesthetics and functions" (p. 59). Lewis (2006) claimed that inquiry facilitates convergent and divergent thinking in engineering design. This study showed that questioning was a critical stage that bridged problem and solution domains. Also, questioning was an entry point to the solution strategies such as designing, predicting, and modeling. Based on these results, the researcher encourages educators to value the inquiry of engineering design as they make the scientific inquiry of science learning (NRC, 2000, 2012). The researcher promotes engineering and technology educators to develop effective questioning strategies to encourage the inquisitive habit of mind by raising inquiry questions such as "what is the problem?" "who is the client?" "how will your team create the prototype, model, or solution?" "how will you record results?" "how will you improve your solution?" or "how will you use your design solution?".

9.5 Conclusion

The ability to solve problems in creative and innovative ways is becoming more critical than ever (Friedman, 2012). Many companies face global competition in producing creative products and services; therefore, our students need to develop creative problem-solving abilities. To support these demands, the educational curricula in the U.S. and other countries focus on building creativity, communication, design, and innovation (Brown, 2008). In the last two decades, many K-12 STEM educational standards have attempted to integrate multiple disciplines using engineering design as a platform to foster students' problem-solving abilities (Common Core State Standards Initiative, 2010; ITEA/ITEEA, 2000/2003/2007; the NGSS Lead States, 2013). When adopting the engineering design approach in schools, appropriate instruction about the engineering design process must build these practical problem-solving abilities.

The journey of this study began with the simple question, "How do students solve engineering problems?" As a technology teacher, the author experienced when students solve engineering problems in the classroom. They tended to show a specific type of behavioral or cognitive pattern. This study attempted to identify the cognitive patterns of problem-solving in young students using Halfin's codes (1973) and sequential analysis (Bakeman & Gottman, 1986). While doing this research, the most exciting moment was when the author checked the statistical results, which were similar to what the study had witnessed in his technology and engineering classes. When teaching technology and engineering, the author met many engineering design process models from textbooks or other teaching materials but often used them without considering why they were created and how to use them. This study does not intend to provide which model is the best or the correct answer but to reflect on the practice of engineering design in the technology and engineering classroom.

One of the biggest takeaways of this study is that engineering design is not just solving a problem, it makes students cognitive thinker, and technology and engineering education plays a significant role in building the ability. Contemporary research from cognitive and learning science indicates that students are active learners, and the primary function of educators is to facilitate student learning by building educative learning environments (McCaslin & Hickey, 2001). As this study indicated, students use various cognitive strategies, including framing problems, analyzing and formulating questions, ideations, modeling, and self-regulation, and managing the group performance in the process of engineering design. With the adoption of engineering into technology education (STEL, 2020), it is important to investigate where the focus of technology and engineering education should reside and what educational outcomes we want to bring into K-12 education. The results of this study will help engineering, technology, and more significant STEM education communities improve understandings of how students undertake engineering design challenges and problem-solving pathways.

References

Adams, R. S. (2002). Understanding design iteration: Representations from an empirical study. In *Common Ground: Proceedings of the Design Research Society International Conference at Brunel University* (pp. 1151–1161). Staffordshire University Press.

Atman, C. J., & Bursic, K. M. (1998). Verbal protocol analysis as a method to document engineering student design processes. *Journal of Engineering Education, 87*(2), 121–130. https://doi.org/10.1002/j.2168-9830.1998.tb00332.x

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education, 96*(4), 359–379. https://doi.org/10.1002/j.2168-9830.2007.tb00945.x

Bakeman, R., & Gottman, J. M. (1986). *Observing interaction: An introduction to sequential analysis*. Cambridge University Press.
Bakeman, R., & Quera, V. (2015). *GSEQ: Generalized sequential 5.1.22*. http://www2.gsu.edu/~psyrab/gseq/
Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6). https://hbr.org/2008/06/design-thinking
Burks, A. (1946). Peirce's theory of abduction. *Philosophy of Science, 13*(4), 301–306. https://doi.org/10.1086/286904
Bruning, R. H., Schraw, G. H., & Norby, M. M. (2011). *Cognitive psychology and instruction* (5th ed.). Pearson.
Chan, J., & Schunn, C. (2015). The impact of analogies on creative concept generation: Lessons from an in vivo study in engineering design. *Cognitive Science, 39*(1), 126–155. https://doi.org/10.1111/cogs.12127
Common Core State Standards Initiative. (2010). *Common core state standards for mathematics.* National Governors Association Center for Best Practices and the Council of Chief State School Officers.
Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education, 101*(4), 738–797. https://doi.org/10.1002/j.2168-9830.2012.tb01127.x
Dorst, K. (2004). On the problem of design problem-problem solving and design expertise. *Journal of Design Research, 4*(2), 126–139. https://doi.org/10.1504/JDR.2004.009841
Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem–solution. *Design Studies, 22*(5), 425–437. https://doi.org/10.1016/S0142-694X(01)00009-6
French, M. J. (1999). *Conceptual design for engineers* (3rd ed.). Springer, London.
Friedman, K. (2012). Models of design: Envisioning a future design education. *Visible Language, 46*(1), 132–153. https://search.proquest.com/docview/1019963104?accountid=13360
Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal, 4*(2), 123–143. https://doi.org/10.1080/10400419109534381
Halfin, H. H. (1973). *Technology: A process approach.* Doctoral dissertation, West Virginia University. *Dissertation Abstracts International, 11*(1), 1111A.
Harfield, S. (2007). On design 'problematization': Theorising differences in designed outcomes. *Design Studies, 28*(2), 159–173. https://doi.org/10.1016/j.destud.2006.11.005
International Technology and Engineering Education Association (ITEA/ITEEA). (2000/2003/2007). *Standards for technological literacy: Content for the study of technology.* Author
International Technology and Engineering Education Association (ITEEA). (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education.* Author
Jin, Y., & Chusilp, P. (2006). Study of mental iteration in different design situations. *Design Studies, 27*(1), 25–55. https://doi.org/10.1016/j.destud.2005.06.003
Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85. https://doi.org/10.1007/BF02300500
Junginger, S. (2007). Learning to design: Giving purpose to heart, hand, and mind. *Journal of Business Strategy, 28*(4), 59–65. https://doi.org/10.1108/02756660710760953
Kim, E., & Kim, K. (2015). Cognitive styles in design problem solving: Insights from network-based cognitive maps. *Design Studies, 40*, 1–38. https://doi.org/10.1016/j.destud.2015.05.002
Koen, B. V. (2003). *Discussion of the method: Conducting the engineer's approach to problem solving*. Oxford University Press.
Kruger, C., & Cross, N. (2006). Solution driven versus problem driven design: Strategies and outcomes. *Design Studies, 27*(5), 527–548. https://doi.org/10.1016/j.destud.2006.01.001
Lewis, T. (2006). Design and inquiry: Bases for an accommodation between science and technology education in the curriculum? *Journal of Research in Science Teaching, 43*(3), 255–281. https://doi.org/10.1002/tea.20111

McCaslin, M., & Hickey, D. T. (2001). Educational psychology, social constructivism, and educational practice: A case of emergent identity. *Educational Psychologist, 36*(2), 133–140.

Mentzer, N., Becker, K., & Sutton, M. (2015). Engineering design thinking: High school students' performance and knowledge. *Journal of Engineering Education, 104*(4), 417–432. https://doi.org/10.1002/jee.20105

Mosborg, S., Adams, R., Kim, R., Cardella, M., Atman, C., & Turns, J. (2005, June). Conceptions of the engineering design process: An expert study of advanced practicing professionals. Paper presented at *2005 Annual Conference*, Portland, OR. https://peer.asee.org/14999

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. National Academies Press.

National Research Council. (2012). *A framework for K12 science education: Practices, cross cutting concepts, and core ideas*. National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. National Academies Press.

Sung, E., Kelley, T. R., & Han, J. (2019). Influence of sketching instruction on elementary students' design cognition: A study of three sketching approaches. *Journal of Engineering Design, 30*(6), 199–226.

Euisuk Sung is an assistant professor of Career & Technology Teacher Education at New York City College of Technology. He studied computer science for his bachelor's degree and worked in a start-up company as a software engineer. After years of working in computer science, he decided to become an educator, which was the most valuable work for his career. He taught in public high schools for nine years and authored several technology education textbooks. He completed his Ph.D. degree in engineering and technology teacher education, and his research interest includes the maker movement, computational thinking, and design thinking.

Todd R. Kelley is an Associate Professor in Technology Leadership and Innovation and joined Purdue University in 2008 upon completion of his Ph.D. at the University of Georgia. His dissertation research was on teaching and learning engineering design in secondary education. Prior to graduate school, Kelley was a high school and middle school technology education teacher for nine years teaching in three school districts in New York state and Indiana. Todd's research focus is in design and cognition seeking to better understand how young students learn design and how design improves STEM education. He joined a team of researchers to create a program to improve learning STEM in elementary grades, and the team was awarded an NSF Math and Science partnership called Science Learning Through Engineering Design (SLED). Todd is currently the PI on an NSF I-Test project called Teachers and Researchers Advancing Integrated Lessons in STEM (TRAILS). TRAILS prepares science and technology education teachers to integrate STEM content through biomimicry inspired engineering design within the context of entomology.

Chapter 10
Assessment of Real-World Problem-Solving and Critical Thinking Skills in a Technology Education Classroom

Susheela Shanta

Abstract In the twenty-first century, Science, Technology, Engineering, and Mathematics (STEM) workers need to be able to utilize their existing knowledge in science and mathematics and solve complex real-world (authentic) problems. Making timely decisions on what disciplinary areas contribute to the creation of a problem and thereby developing a reasonable solution requires critical thinking. Together, problem-solving, and critical thinking are touted as the most important skills (or abilities) needed by employees for tackling the challenges of this century. Also, having the necessary background in science and mathematics, being able to communicate well, and working with diverse teams comprised of people from all walks of life are all essential for those seeking employment. Teaching students to problem-solve in real-world STEM contexts is known to be complex and there are limited assessment instruments appropriate for classroom use. Ad hoc trial and error approach to problem-solving without the use of science and mathematics-based knowledge can be detrimental in the real-world context. Herein lies the challenge: faced with a design problem out of the context of the classroom, students may not readily recognize the STEM domains applicable to solving the problem. Engineering, through its hands-on and design-oriented approach, offers a platform in K-12 grades for integrating content and practices in the STEM fields and provides opportunities for higher-order learning. This is because higher order cognitive demands (as per Blooms Taxonomy, *apply*, *analyze*, *justify*, *and create* are higher-order thinking abilities) are made when engaged in design-based problem-solving experiences. Assessment of engineering problem-solving skills in the context of technology education or in engineering education in K-12 grades is problematic because it is time-consuming to design the lessons for each aspect of the design process and evaluate problem-solving, as problems encountered may be unique to each team or individual. Frequently, students engage in their own unique and sometimes ad-hoc trajectories in defining a problem and set about developing alternative solutions. Similarly, assessment is also time-consuming and cumbersome because of a multitude of reasons: e.g., teamwork and collaboration require peer assessments and rubrics, creativity and communication are

S. Shanta (✉)
Governor's STEM Academy at BCAT in Roanoke County Schools, Charlotte, USA
e-mail: sshanta@vt.edu

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_10

multifaceted and require separate assessments for each facet, and there is no right or wrong solution thereby requiring subjective assessments based on many factors. For assessment in the classroom, while it is possible to prescribe a process to be followed and create benchmarks regarding every aspect of an engineering design process, doing so will eliminate the authenticity of student performance. Furthermore, students being grade-focused, tend to follow instructions closely which then inhibits their creativity and investigation using the iterative process to evaluate and optimize their solution. In this chapter, we describe an assessment instrument with metacognitive questions and a related rubric for scoring student problem-solving skills when faced with an authentic design challenge. Metacognitive questioning directs students' thinking and responses to specific assessment items measured by the related rubric. This assessment instrument and its related scoring rubric can be used by teachers for delivering instruction and later for evaluating students' performance by removing some of the subjectivity in evaluation.

Keywords Critical thinking · Problem-solving · Design-based pedagogical approach · Authentic design challenge · STEM education · Integration · Classroom assessment

10.1 Research Focus and Questions

Twenty-first-century learning outcomes occur when students can gain a deep understanding of science and math concepts, and use the content and practices of these disciplines with the content and practices of technology and engineering to solve problems situated outside the classroom. For this to occur, integration of the disciplines in the instructional approach is essential (National Research Council (NRC), 2009; Sanders, 2012). Engineering (through its characteristic design-based pedagogical approach) offers a platform in K-12 education for integration of content and practices in the STEM fields and provides opportunities for higher order learning because of higher cognitive demands in critical thinking and design-based problem-solving experiences (National Academy of Engineering (NAE) and NRC, 2014; Katehi et al., 2009; Sheppard et al., 2006; Wells, 2016). In an integrative STEM education program, five of the twenty-first-century skills (Collaboration, Creativity, Communication, critical thinking (CT) and problem-solving (PS) and citizenship) are expected to be the focus of instruction. However, CT and PS skills are not assessed in traditional science and mathematics standardized testing and rarely assessed in technology education. When students are tested for their problem-solving abilities in the traditional classroom the focus is on the extent of the correctness of the end result, and rarely, if ever, on the reasoning or procedures leading to the result (Docktor & Heller, 2009; Shavelson et al., 2003; Steif & Dantzler, 2005). Furthermore, the content knowledge tested is related to what has been recently taught in the classroom, which does not require the solver's demonstration of metacognitive processes involved in CT that require selecting the discipline-specific content knowledge. Among the reasons behind the lack of focus on CT and PS in assessments is the lack of time to allow students an opportunity to explore various alternatives for designing a solution to the problem and pick the solution that best suits the various factors that affect success. Instead, students are provided instructions and materials for designing the solution which in turn lead students in the direction of a design solution that is the instructors' prescribed solution. It could also be true that the instructors lack the engineering or science background necessary to provide students the depth of instruction needed to facilitate students' explorations. Whatever the reasons, the result is that CT and PS skills are often not taught and/or assessed in the classroom which leads to students' lack of experience in these skills.

This study was intended to address the lack of research to support the benefits of technology/engineering design-based learning (T/E DBL) as a signature pedagogical approach of integrative STEM education, for "conceptual attainment" (Zuga, 1995, p. 67) and "problem solving" (Zuga, 2000, p. 2) skill development as outcomes of technology education (Cajas, 2000; Kolodner, 2000; Zuga, 2000). Furthermore, the development of instruments for assessment was a necessary precursor to discovering the benefits of T/E DBL. A review of published literature in the first fifteen years of the twenty-first century resulted in identifying relevant research studies on students' problem-solving (PS) skills in physics and its sub-discipline of mechanics, which contributed to the development of the instruments and the data collection in this study. In this exploratory and descriptive study, we attempted to add to the research base regarding the benefits of a T/E design-based pedagogical approach in developing problem-solving and critical thinking skills among students in a program that emphasizes STEM education.

The specific questions in the study were:

1. To what extent are students successful in using content and practices of engineering, science, and mathematics for solving an authentic design-based problem outside the confines of the classroom where the subjects were originally taught?
2. How are the key student abilities in CT and PS correlated to overall student success in solving the problem? Specifically, what is the correlational strength of the relationship of the key student abilities with their overall success in solving the authentic design-based problem?

10.2 Research Methods and Design

For the problem-solving activity in this study, a design-based problem was chosen. Design-no-make (DNM) was introduced by David Barlex in 1999 through the Young Foresight initiative (Barlex, 2003). At the time it was introduced, it was used to help focus students' learning, and teachers' instruction toward the design phase instead of making the designed product. To this day, Technology education classrooms tend to be more hands-on in their approach and students in those classrooms tend to be naturally more engaged in the making aspect of their design solutions. Research has shown that the DNM approach is valuable in helping students explore a wide range of design criteria, helps develop more understanding of the technological concepts, and that students enjoyed the experience as well (Barlex & Trebell, 2008). From an instructional perspective, the distractions of making the prototype were removed from the learning experience, and thus allowed students to explore various ideas and concepts in greater depth. Students spend more time on the best possible design solution through examination of various alternatives that could yield a solution and which of those would best satisfy the criteria for a successful outcome. The resulting design solution when implemented by the students in the "making" aspect also becomes a better process where students' deeper understanding of their design results in increased efficiency and engagement in troubleshooting or problem-solving during manufacture. In the current study, this type of DNM challenge was suitable and instrumental in revealing students' use of schematic and strategic knowledge domains (previously described) correlated to CT and PS skills.

This study examined student responses to a design-no-make challenge (DNMC) as a means for assessing their higher order thinking skills evidenced by their selection and utilization of science and math content to solve the problem described in the DNMC. The students were from a specialized school (the Academy) that has as its core objective, the cultivation of engineering ways of thinking and acting so that students would be better prepared for their college education and future careers in STEM disciplines. This school will be referred to as the Academy in this chapter. In K-12, especially in the middle school (6th–8th) and high school (9th–10th) grades, often tech-ed courses are offered for students to gain experience with technological and engineering (T/E) design, though not all students take these classes and there is not enough continuity of exposure to T/E design over the years. The DNMC with prompts was developed using a physics-based authentic problem typical of the types of problems encountered by humanitarian workers of Virginia Tech, engineering students in their work in Malawi (http://www.beyondboundaries.vt.edu/team-malawi.php). In discussions with the co-founder, Dr. Andre Muelenaer, and physics educators in secondary education, the design challenge was first developed.

The metacognitive question prompts were developed to elicit responses to demonstrate key student abilities (SAs) as identified in this study. The scoring rubric for the DNMC response was adapted from the rubric developed by Docktor (2009) to measure the key SAs identified as indicators of students' abilities to solve authentic problems outside the classroom where the related subjects were first learned. The domain of the problem was situated in the physics and mathematics content areas. Both physics and mathematics were components of the curriculum in the Academy where the study was conducted. Researchers have found that lack of literacy in these two content areas (physics and mathematics) as contributing to the challenges faced by undergraduate students in engineering programs (Budney et al., 1998; Steif & Dantzler, 2005). One of the reasons students drop out or transfer out of engineering programs is that they are inadequately prepared to apply the foundational knowledge in these subjects (ibid). The DNM was therefore developed with a combination of

Description of Scenario

A small village in a third world country has determined that its most pressing need is for safe drinking water. A volunteer team determined the location of an appropriate underground spring and dug the well. The well is 10.0 meters deep and one way to access the water in the well, would be to lower buckets into the well. The concerns with using buckets to retrieve the water are, that the buckets will become dirty over time and defeat the purpose of the safe drinking water, and, using buckets would be time consuming, difficult, and create hardship for those who need the water. The volunteer team decided to use an electric submersible pump to bring the water safely and cleanly to the surface for storage and use.

Challenge

Your task in this challenge, is to design a suitably sized (power – measured in horsepower – hp) and priced (dollars) submersible pump to supply water at a rate of 35gal/min. Remember, in America we sell electric motors in horsepower, not watts, and 1.0 hp = 746 W. For pricing, use the information provided in the attachment.

Fig. 10.1 Design-no-make challenge

physics (work and power) concepts and algebraic manipulation of formulae with attention to applied unit conversions.

Data were collected on students' utilization of the design-based approach and acquired science and mathematics concepts in solving an authentic problem (DNMC) using a rubric, developed as part of this study, to score students' responses to the presented challenge problem. The description and the challenge provided to students is shown in Fig. 10.1.

The following questions asked of the students (in their design-challenge handout) were prompts designed to reveal student thinking:

Q1 What is your understanding of the challenge described above? Describe using your own words, in a few sentences.

Q2 Based on what you wrote above, draw a sketch to describe the scenario, and label the sketch to show the information provided above (e. g. the depth of the well is 10 m). Use variables for what you do not know.

Q3 How could you determine the power of the water pump? State any laws and equations you would use and explain your strategy in a few sentences.

Q4 Based on your response to question 2 go through the process you have outlined and show your calculations to determine the power of the pump (in horsepower).

Q5 Based on your work in question 3, what is the power of the motor you need? Using the motor pricing information provided, which motor would you pick and how much will it cost?

For the last question, a price sheet was provided to the students, which included four options of submersible pumps with various horsepower options and their related prices.

Research into the nature and characterization of problem-solving over several decades has identified a set of student abilities requisite of success for solving authentic problems outside the confines of a typical classroom (Simon and Newell, 1972; Polya, 1980; Perkins & Salomon, 1989; Martinez, 1998; Jonassen et al., 2006). Specifically, these student abilities are (1) useful description, both symbolic and descriptive, (2) recognition and selection of relevant content applicable to the problem, (3) use of the principles and practices of specific content identified to solve the problem, and (4) adherence to a devised logical strategy for solving the problem. This research study used parts of the previously discussed studies to develop, validate, and utilize an assessment scoring rubric (Fig. 10.2) to score student responses.

10.3 Findings

Data collected was from scoring the students' responses to the questions on the design challenge using the rubric. These responses provide insights into students' utilization of the design-based approach and acquired science and mathematics concepts used to solve an authentic problem (DNMC) situated outside the confines of the classroom where those disciplines are taught. The metacognitive questions (listed before) in the DNMC were specifically developed to uncover students' ability to restate a problem in words showing their understanding of the critical aspects of the provided information and to create a sketch, not unlike the idea of free-body-diagrams (FBD) taught in Physics and Mechanics. The third and fourth questions were used to direct students to identify and recall specific content in physics and mathematics that would help them solve the problem at hand. The last question was aimed at getting students to make a choice that would meet the criteria for a successful solution, specifically—suitably sized and priced, from the available choices. This also reveals if students had a logical progression of connected concepts and calculations that were used to select the final product.

Scorers would need to score the responses using the rubric to convert the qualitative responses to quantitative measures for each question that would result in a cumulative score. For this, two scorers trained on using the scoring rubric previously developed in a pilot study scored the students' written responses to the DNMC from the main study. The scores obtained were then analyzed to answer the research questions.

The primary finding was that students immersed in an integrative STEM education program where the pedagogical approach is design-based learning (the Academy), performed significantly better (as assessed using their overall success score) in designing a solution to the design-no-make-challenge (DNMC) when compared with the performance of students in a traditional classroom. A secondary conclusion of this study was that four specific student skills (out of five identified in this study) that are collectively known as problem-solving skills, were strongly related to students' performance in authentic problem-solving. The following sections describe the findings in detail.

Q1: USEFUL DESCRIPTION (Specific to a given problem)	**5** The description provides appropriate details and is complete.	**4** The description provides appropriate details but contains 1 omission or error.	**3** The description provides appropriate details but contain 2 omissions or errors.	**2** The description provides details but contains 3 omissions or errors.	**1** There is a description contains more than 3 omissions or errors or is incorrect.	**0** The response does not include a description.
Q2: SKETCH (Contains dimensioning, legible, and correct units of measurement, labels for specific features or known items.)	The sketch provides appropriate details and is complete.	The sketch provides details but contains 1 omission or error.	The sketch provides details but contains 2 omissions or errors.	The sketch provides details but contains 3 omissions or errors.	There is a sketch but contains more than 3 omissions or errors or is incorrect.	The response does not include a sketch.
Q3: SPECIFIC APPLICATION OF PHYSICS	**5** The specific application of physics is appropriate and complete.	**4** The specific application of physics 1 omission or error.	**3** The specific application of physics contains 2 omissions or errors.	**2** The specific application of physics contains 3 omissions or errors.	**1** The specific application of physics is inappropriate or has more than 3 omissions or errors or is incorrect.	**0** The specific application of physics is missing.
Q4: Application of Mathematics	**5** The mathematical procedures are appropriate for solving this problem and complete.	**4** The mathematical procedures are appropriate for solving this problem with 1 omission or error.	**3** The mathematical procedures are appropriate for solving this problem with a 2 omissions or errors.	**2** The mathematical procedures are appropriate for solving this problem with 3 omissions or errors.	**1** The mathematical procedures are inappropriate for solving this problem or has more than 3 omissions or errors, or is incorrect	**0** The mathematical procedures are entirely missing.
Q5: LOGICAL PROGRESSION	**5** The problem solution is clear, focused, logically connected, and complete.	**4** The solution is clear and focused with 1 logical inconsistency and complete.	**3** Parts of the solution are unclear, unfocused, and has 2 logical inconsistencies.	**2** Most of the solution parts are unclear, unfocused, and 3 logical inconsistencies.	**1** The problem solution is unclear, unfocused, and inconsistent.	**0** There is no evidence of logical progression.

Fig. 10.2 Final modified scoring rubric

Research Question 1: Overall Performance of Students in the program

Research Question 1 (RQ1) was associated with measuring the extent to which students were successful in solving an authentic design-based problem. The overall performance of students was assessed by the overall success score (OSS) achieved on the written responses to the DNMC. The sum of the individual scores for the five

Table 10.1 T-test for student scores

	Test value (hypothesized mean) = 12 (Bootstrap = 1000 samples)					
	t	df	Sig. (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Overall success score	3.708	10	0.004*	4.455	1.78	7.13

components representing five key student abilities (SAs) identified as the essential aspects of problem-solving and critical thinking resulted in the OSS. The five SAs are described in the following paragraph.

Useful Description reflected a solver's skill in identifying the relevant information in the problem statement or design challenge that would be useful for consideration in developing the solution. *Sketch* reflects a solver's ability to represent the information in the problem symbolically and graphically stating qualitative expectations and quantitative known values described in the problem. Student abilities associated with *Specific Application of Physics* and *Application of Mathematics*, reflect a solver's ability to select relevant physics and mathematical content or principles and applying them to the specific context of the problem. *Logical Progression* reflects a solver's ability to communicate reasoning and laying out a clear and focused strategy in achieving the goal.

From the data presented in Table 10.1, students achieved an average score of 16.45 points (out of 25 possible points) which represents a 65.8% score. The *t*-test results showed statistical significance to the higher mean overall performance score of students in the Academy (higher mean by 4.455; 95% CI, 1.78 to 7.13) when compared with a hypothesized mean which represented a 48% score). It can be inferred that the students in the Academy had a higher mean performance score than the hypothesized mean used as a benchmark. The hypothesized mean was obtained from the pilot study conducted in a traditional classroom (not within the Academy), where the students were completing the same physics course (using the same curriculum) as students in the Academy. The calculated effect size (Cohen's *d*) of 0.8 indicated a large effect which implies that the strength of significance of the *t*-test is large enough to be significant.

Research Question 2: Correlations between Overall Performance and Student Abilities

Research Question 2 (RQ2) was aimed at investigating the strength of the relationships between students' overall performance (OSS) and each of the five key student abilities (SAs) in designing a written solution to an authentic problem as posed in the DNMC. What follows is a discussion of the conclusions drawn from the data analysis.

For a small sample size, as in this study, it is recommended that the adjusted correlation be calculated and used for interpretations of the strength of correlation

Table 10.2 Pearson's (PPM) correlations between OSS and the five SAs

Research question number (RQ)	Student ability (SA)	PPM statistic (*r*)	Significance level (p)	Adjusted correlation statistic (r_{adj})
Q2a	Useful description	0.121	0.723	N/A
RQ2b	Sketch	0.635	0.036*	0.581
RQ2c	Specific application of physics	0.916	0.000**	0.821
RQ2d	Application of mathematics	0.953	0.000**	0.898
RQ2e	Logical progression	0.918	0.000**	0.826

Note *Significance at $p < 0.05$; **Significance at $p < 0.01$

between the two variables. A correlational statistic value greater than 0.5 indicates a strong correlation (Cohen, 1988). Table 10.2 summarizes the (Pearson's) correlational strengths between the overall performance (OSS) and the five student abilities (SAs).

To reiterate, *Sketch* reflects a solver's ability to represent the information in the problem symbolically and graphically stating qualitative expectations and quantitative known values described in the problem. Student abilities associated with *Specific Application of Physics* and *Application of Mathematics*, reflect a solver's ability to select relevant physics and mathematical content or principles and applying them to the specific context of the problem. *Logical Progression* reflects a solver's ability to communicate reasoning and laying out a clear and focused strategy in achieving the goal. Results of the correlational analysis showed that these four SAs were strongly correlated (significance at $p < 0.05$) to their overall performance (OSS) in designing a solution to the DNMC (presented in the adjusted correlation statistic column in Table 10.2). The resulting conclusion drawn from this analysis is that these student abilities or skills are critical to students' successful problem-solving in situations outside the context where the specific content was learned.

Contributions of Specific SA's toward the Variability in Students' Overall Performance

The coefficient of determination is calculated as the square of the correlation coefficient. This statistic represents the percent of the data points that are closest to the line of best fit in the model and is a measure of how well the regression line represents the data. A higher coefficient is an indicator of better goodness of fit and can provide a good indication of prediction of the variations of one variable with respect to the other in the regression model (Howell, 2010). By no means is this an indication of causality, but it best represents a measure of variability in OSS that can be predicted

Table 10.3 Pearson's correlations and calculated coefficient of determination for the SAs

Student abilities	PPM correlation (r)	Coefficient of determination (r^2)
Useful description	0.121 ($p > 0.05$)*	0.015 (1.5%)
Sketch	0.635 ($p < 0.05$)	0.403 (40.3%)
Specific application of physics	0.916 ($p < 0.01$)	0.839 (83.9%)
Application of mathematics	0.953 ($p < 0.01$)	0.908 (90.8%)
Logical progression	0.918 ($p < 0.01$)	0.843 (84.3%)

*Correlation is not statistically significant at the 0.05 level

by the variability of those SA's. The calculated coefficient of determination for each of the five correlational analyses is summarized in Table 10.3.

The most significant contributions of students' abilities attributable to their overall success in designing a solution to the DNMC (from the regression model) come from their ability to select and utilize relevant content and practices in science (84%) and mathematics (91%), and from their ability to logically progress through the process (84%) to design a solution to an authentic T/E design problem. These SA's were found to be strongly represented by the correlational (linear) model in this dataset (Table 10.2).

10.4 Contributions Toward Teaching and Learning

The primary conclusion of this study is that four specific student abilities (out of five identified and used in this research study) are strongly related to students' performance in authentic problem-solving. The four specific abilities are—*Sketch, Specific Application of Physics, Application of Mathematics, and Logical Progression.* In other words, these skills are critical to students' successful problem-solving in situations outside the context where the specific content has been learned. A secondary conclusion is that students immersed in an integrative STEM education program performed significantly better (as assessed using their overall success score) in designing a solution to the design-no-make-challenge (DNMC) when compared with a hypothesized mean for students in a traditional classroom.

These conclusions have direct implications for instruction in K-12 T/E design education, student learning and assessment, and engineering program design in secondary schools. One of the primary motivations for this research was the need for STEM literate graduates prepared for the problem-solving and critical thinking skills needed to tackle the challenges in the twenty-first century. US students lag in science and mathematics literacy and many studies have linked the lack of preparation of students to use high school science and mathematics knowledge to high rates of attrition in STEM programs at the undergraduate level (NCES, 2012; Pope et al., 2015; Budney et al., 1998; Steif & Dantzler, 2005).

The mean overall performance of students in the academy was shown to be statistically significant. The practical interpretation of this statistically significant difference does not necessarily mean that students' overall performance in the DNMC or the situational problem-solving performance was good. The percentage score of mean OSS (65.8%) represents a C grade performance. The lowest OSS score achieved was 10 points (40% or F grade) and the highest was 23 points (92% or A grade). Nine of the eleven students in the sample achieved exactly or above passing grades (greater than or equal to 15 points or 60% and above). Therefore, the average student success score does not represent good performance in demonstrating problem-solving skills on the DNMC. Of course, this study was not designed to identify the strength of successful problem-solving skills, but rather, to identify the skills that strongly correlate too successful problem-solving. Yet, this lack of strong performance in problem-solving success raises curiosity. We speculate that many factors could have contributed toward the low-performance scores associated with this study. One possible factor could lead us to surmise that while the students in the academy were high achievers and generally maintain high subject grades, the overall problem-solving performance still lacking could imply a systemic instructional deficit of focusing instruction on the individual subject content knowledge proficiency embedded in the standardized testing culture.

A shift in the orientation of teaching toward the application of the content through authentic mini problem-solving activities where student's gain more experience in utilizing the various subject-specific content in designing solutions to the problems presented. Additionally, it is rare that teachers focus project-based learning (PBL) on the integration of science, mathematics, and communication in authentic (real-world) design challenges in the US. This may be the result of a lack of time to plan or implement such instructional approaches. Teachers have back-to-back classes that they teach through the day and if they have time, it is usually to contribute their time to assisting with supervising lunchrooms or hallway discipline. Usually, the curriculum is also standardized and scripted by the school district and the State, which again, is focused on achieving standards that can be easily measured.

This study generated preliminary and limited data on the benefits of the technological/engineering design-based learning (T/E DBL) pedagogical approach within an integrative STEM education program as implemented in the Academy where engineering, mathematics, and science courses are integrated and progressively sequenced within the four-year curriculum. Further research on student learning, specifically on how students select and utilize science principles previously learned in solving T/E design-based problems, using a qualitative approach would provide additional insights into student learning and transfer of their learning. Such a study would potentially involve developing design-no-make challenges that are aligned with the various grade levels. These challenges would have to be evaluated for grade-level alignment, validity, and reliability by instructional experts in science, technology, engineering, and mathematics.

The correlational analysis between students' abilities and overall performance revealed that specific skills involving selecting and utilizing science and mathematics content and practices were statistically significantly related to the overall performance in designing a solution to the Design-No-Make Challenge (DNMC) provided. The implications from these results are that when designing a solution to the DNMC, students' abilities to recognize, recall, select and utilize science and mathematics content and practices are significant to successful T/E design-based problem-solving (outside the confines of the classroom where the science or mathematics was learned). This finding may have broader implications for classroom assessment and student learning. However, further research will be needed to explore those avenues for improving student outcomes.

From a practical perspective, the lower average (percentage) scores in the Specific Application of Physics (61.8%) and Application of Mathematics (52.8%) reveal that students need to improve their ability to recognize, select and utilize relevant science and mathematics content and practices in designing a solution to an authentic T/E design-based problem (such as the DNMC). This could imply that instructional strategies need to be further strengthened to help students learn to select and utilize science and mathematics in problem-solving in diverse contexts. There may be reason to also investigate the same skills in students in the lower grades to focus on helping develop these skills at an earlier grade level for all students. The statistically significant coefficient of determination (r^2) associated with the student abilities of *Specific Application of Science*, *Application of Mathematics* and *Logical Progression* in contributing to the variation of their *Overall Success Score* corroborates the importance of these student abilities in engineering design-based problem-solving.

The rubric (refer to Fig. 10.2) developed in this study has the potential to be used as an assessment tool in the technology education classroom. The rubric has five scoring categories that relate to the five skills deemed to be critical for successful problem-solving in an authentic context. Teachers in Virginia (and probably everywhere in the US) are required to demonstrate student growth as a means of setting a performance goal for self-evaluation. Specific student abilities could be targeted, or the overall success score can be a benchmark for demonstration of student growth using pre-and post-assessments. While teachers in core disciplines use statewide testing for setting their performance goals, some technology education (Tech-ed) teachers use industry credentialing for specific technology for their performance goals, teachers in those disciplines or subjects that do not have credentialing (such as engineering in high school) can use the modified rubric developed in this study to set up performance goals and indicators.

10.5 Suggestions for Technology and Engineering Educators

To develop students' ability to problem-solve in authentic (i.e., real-world) contexts, it is essential to utilize a technological and engineering design-based approach with an emphasis on two key aspects:

(1) Select a design challenge that is based on real-world problems, and

(2) Create an intentional focus on developing the five skills identified in this rubric.

First, instructors need to find authentic, relatable problems that are community-based so that it becomes relevant to the students. Examples might be based on water conservation, waterway clean-up efforts, and rainwater harvesting, storage, and distribution. There could be any other community-based problem that students may also help identify as a preliminary exercise in problem identification, which is also an integral part of engineering design. Taking time to do this will not only make the topic relevant to the community within which students are situated, but also inherently motivate students to become engaged as they relate to the context. This will require that the instructors provide some guided discussions that lead students to topics or areas relevant to the context of the lesson or unit.

Instructors could then utilize the five student abilities (Useful *Description, Sketch*, *Specific Application of Science*, *Application of Mathematics*, and *Logical Progression)* identified in this study as a method to develop their questions and questioning strategies. By utilizing a backwards-design approach, instructional goals could be aligned with the development of the specific student abilities which can then provide a focus on those aspects during classroom instruction.

In traditional tech-ed classrooms in the USA, assessments are focused on the skills outlined as competencies in the Career and Technical Education (CTE) course framework (CTE, 2015). This framework provides guidance and curricula set forth by the Department of Education, for vocational and technical education in the United States. Specific competencies in this framework are measurable skills to be attained by students who take the career and technology education coursework. As previously noted, a lack of focus on solving authentic problems is reflected in the competencies and therefore the shortcomings are reflected in students' poor performance in any testing modalities that test problem-solving that are not directly related to a discipline (such as physics or mathematics) and/or in a particular discipline or classroom. Examples would be in competitions that throw out design challenges that test students' problem-solving skills situated in a complex real-world simulation.

A follow-up study to this study could focus on creating templates for DNMC development and rubrics to add to the richness and usefulness of resources available for Technology-education (Tech-ed) courses and focus on solving authentic problems not currently addressed by the curricula. The rubric categories used to assess the problem-solving skills of students in this study could be further expanded for use by Tech-ed educators to prepare instructional goals for their teaching and to assess their students' performance. Such a study could be designed to use a Delphi approach with disciplinary experts to develop content areas suitable for design-no-make challenges in the secondary school curriculum, and the related question prompts needed to effectively focus student thinking on the significant student abilities identified in this study.

Furthermore, the modified rubric could also be aligned for use with the design challenges developed. Such resources could help introduce the twenty-first century skill of "Critical thinking and problem solving" (P21, 2015a) more effectively within traditional Tech-ed courses and in non-Tech-ed science classrooms where engineering design is introduced. Classroom teachers who are accustomed to using project-based learning would have a ready-to-use rubric without the time commitment involved in creating a method of assessing their assignments given to their students. Additional refinement of the modified rubric used in this study would be needed to ensure its usefulness in the sciences and technology education, along with a study to establish the reliability of the rubric.

References

Barlex, D. (2003). Considering the impact of design and technology on society—the experience of the Young Foresight project. In J. R. Dakers & M. J. Devries (Eds.), *The place of design and technology in the curriculum PATT conference 2003* (pp. 142–147). University of Glasgow.

Barlex, D., & Trebell, D. (2008). Design-without-make: Challenging the conventional approach to teaching and learning in a design and technology classroom. *International Journal of Technology and Design Education, 18*(2), 119–138.

Budny, D., LeBold, W., & Bjedov, G. (1998). Assessment of the impact of freshman engineering courses. *Journal of Engineering Education, 87*(4), 405–411.

Cajas, F. (2000). Research in technology education: What are we researching? A response to Theodore Lewis. *Journal of Technology Education., 11*(2), 61–69.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Earlbaum Associates.

Docktor, J., & Heller, K. (2009). Robust assessment instrument for student problem solving. In *Proceedings of the NARST 2009 annual meeting*. Retrieved from http://groups.physics.umn.edu/physed/People/Docktor/research.htm#Research_Documents

Howell, D. C. (2010). *Statistical methods for psychology* (7th ed.). Cengage Wadsworth.

Jonassen, D. H., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 1–14.

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects (Committee on K-12 Engineering Education, National Academy of Engineering and National Research Council).* National Academies Press.

Kolodner, J. L. (2000). The design experiment as a research methodology for technology education. Paper presented at AAAS Technology Education Research Conference, Washington DC. Retrieved from.

Martinez, M. E. (1998). What is problem solving? *The Phi Delta Kappan, 79*(8), 605–609. http://www.project2061.org/events/meetings/technology/papers/Kolodner.htm

National Academy of Engineering & National Research Council. (NAE & NRC). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. The National Academies Press.

National Academy of Engineering (NAE) & National Research Council (NRC) (2014). *STEM integration in K-12 education: Status, prospects, and an agenda.* Washington, DC: The National Academy Press.

National Center for Education Statistics (NCES) (2012). U.S. department of education—institute of education sciences, trends in student performance: International trends in average scores. Retrieved on September 24, 2016 from http://nces.ed.gov/surveys/pisa/pisa2012/pisa2012highlights_6a_1.asp

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Prentice-Hall Inc.

Perkins, D. N., & Salomon, G. (1989). Are cognitive skills context bound? *Educational Researcher, 18*(1), 16–25.

Polya, G. (1949/1980). On solving mathematical problems in high school. In S. Krulik & R. Reys (Eds.), *Problem solving in school mathematics: 1980 yearbook* (pp. 1–2). Reston, VA: National Council of Teachers of Mathematics.

Pope, D., Brown, M., & Miles, S. (2015). *Overloaded and underprepared: Strategies for stronger schools and healthy successful kids*. Jossey-Bass.

Sanders, M. E. (2012). Integrative stem education as best practice. In H. Middleton (Ed.), E*xplorations of best practice in technology, design, & engineering education*, vol. 2 (pp. 103–117). Griffith Institute for Educational Research, Queensland, Australia. ISBN 978-1-921760-95-2.

Shavelson, R., Ruiz-Primo, M. A., Li, M., & Ayala, C. C. (2003). *Evaluating new approaches to assessing learning*. National Center for Research on Evaluation, Standards, and Student Testing, Los Angeles, CA.

Sheppard, S., Colby, A., Macatangay, K., & Sullivan, W. (2006). What is engineering practice? *International Journal of Engineering Education, 22*(3), 429–438.

Steif, P. S., & Dantzler, J. A. (2005). A statics concept inventory: Development and psychometric analysis. *Journal of Engineering Education, 94*(4), 363–371.

Wells, J. G. (2016). Efficacy of the technological/engineering design approach: Imposed cognitive demands within design-based biotechnology instruction. *Journal of Technology Education, 27*(2), 4–20.

Zuga, K. F. (1995). *Review of technology education research*. Paper presented at the Technology Education Issues Symposium, June 23–29, 1996, Maui, Hawaii.

Zuga, K. F. (2000). Thoughts on technology education research. In *Proceedings of the first AAAS technology education research conference*, Washington, DC.

Susheela Shanta earned her bachelor's degree in Civil Engineering from India, a Master of Urban Planning degree from the SUNY at Buffalo, NY and more recently, a doctoral degree in Curriculum and Instruction: I-STEM Ed from Virginia Tech. Since 2009, Susheela has been teaching math, engineering courses, and directing the high school engineering program in the Governors STEM Academy in Roanoke County, VA, and teaches foundational engineering courses as adjunct faculty at Roanoke College, VA. In addition, she has been involved in K-12 grades engineering curriculum development with the Department of Education in Virginia and at the national level through a consortium of educators (AEEE—Advancing Excellence for Engineering Education). Providing authentic engineering design experiences for students through partnerships with industry and the community are central to her teaching practice. Her research interests are focused on teaching and learning real-world (authentic) problem-solving and critical thinking skills through the T/E DBL within an integrative STEM education environment.

Chapter 11
The Importance of Spatial Ability Within Technology Education

Jeffrey Buckley, Niall Seery, Donal Canty, and Lena Gumaelius

Abstract Understanding the factors that impact learners with respect to their academic achievement is critical for enhancing educational provision, and the nature of these factors can vary widely. They could be, for example, cognitive, conative, physiological, or physical. With increased understanding of such factor's teachers can better meet learner needs. Investigations into individual differences are not uncommon within technology education, for example much work has been conducted in the area of attitudes towards technology. However, research into individual cognitive differences is an emerging space. In light of the overwhelming evidence illustrating that spatial ability, commonly described as the ability to generate and manipulate abstract visual images, is positively associated with STEM educational performance and retention, understanding the role of spatial ability in technology education is important. Acknowledging the potential implications of such insight but recognising the lack of contextual evidence, this chapter describes the results of a series of studies conducted with the aim of supporting the development of theory and suggesting recommendations for practice with respect to spatial ability within technology education. A literature review of the extant literature on spatial ability was conducted, and four quantitative studies examined the theorised positionality of spatial ability within technology education, and its relationship with authentic problem solving and other cognitive factors.

Keywords Spatial ability · Technology education · STEM education · Intelligence · Educational performance

---

J. Buckley (✉) · L. Gumaelius
KTH Royal Institute of Technology, Stockholm, Sweden
e-mail: jbuckley@kth.se

J. Buckley · N. Seery
Technological University of the Shannon: Midlands Midwest, Westmeath, Ireland

D. Canty
University of Limerick, Limerick, Ireland

L. Gumaelius
Mälardalens Högskola, Västerås, Sweden

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_11

11.1 The Questions Asked and Why They Are Important

There is a wide range of variables that teachers need to contend with when teaching young people. Detterman (2016) categorises these into student variables and school variables. Student variables describe characteristics unique to each individual student, such as intelligence and motivation, while school variables refer to aspects of schooling which affect groups of students within a school, such as teacher quality and class size. Understanding the impact of different variables on desirable student outcomes offers the potential to enact meaningful educational change as interventions such as policy development or pedagogical refinement could target impactful factors. Relating to this, Detterman (2016) identified student variables as being able to account for approximately 90% of the variance in student academic achievement and school variables as accounting for approximately 10% of this variance. More specifically, he found that individual differences in intelligence alone accounted for between 50 and 80% of the total variance, and this finding has seen large scale corroborating evidence from O'Connell (2018) and Smith-Woolley et al. (2018).

In parallel to the evidence which indicates a relationship between intelligence and academic achievement, specifically in science, technology, engineering, and mathematics (STEM) fields substantial evidence links spatial ability, a factor of intelligence, with performance and retention. Wai et al. (2009) present longitudinal evidence for this, and there is additional evidence linking spatial ability to specific subject areas such as design and technology (Buckley et al., 2019c; Khoza, 2017; Lin, 2016), mathematics (Cheng & Mix, 2014; Sorby et al., 2013), physics (Kozhevnikov et al., 2007) and computer programming (Jones & Burnett, 2008). Further to this and important from an educational perspective is that unlike intelligence (Owen et al., 2010; Simons et al., 2016), spatial ability can be developed through targeted educational interventions (Uttal et al., 2013) and this can transfer to improved performance and retention (Sorby et al., 2018).

Based on this evidence, the relationship between spatial ability and academic achievement became the focus of this work. While there are many theories as to why spatial ability is associated with STEM outcomes, there is yet to be a unifying causal explanation which limits the capacity for the translation of evidence into practice. Existing theories include quite direct relationships such that STEM activities often involve the need to mentally rotate objects (such as when imagining molecular structures in chemistry), interpret cross sections (such as in interpreting x-rays in medicine) and imagine exploded views (such as in understanding the components of an electrical plug-in technology), and as such it is theorised that correlations exist as a result of educational activities mirroring spatial processes (e.g. Atit et al., 2020; Gaughran, 2002; Uttal & Cohen, 2012). Other theories relate to roles of additional cognitive mechanisms such as spatial ability being predictive of STEM education performance through an interaction with relevant discipline knowledge (Hambrick et al., 2012) or by affecting information processing in students working memories (Hyland et al., 2018, 2019). In an effort to contribute towards a causal theory, the following research questions (RQ) were developed which placed specific emphasis on spatial ability being viewed as a factor of intelligence:

RQ1 How does the context of technology education impact research investigate the relationship between intelligence, in particular spatial ability, and STEM education?
RQ2 How do levels of spatial ability affect problem solving performance in technology education?
RQ3 What is the nature of the current evidence which illustrates the correlation between spatial ability and STEM education?
RQ4 How is spatial ability perceived to align with technology teacher education students' perceptions of intelligence in STEM?
RQ5 How is spatial ability psychometrically related to other perceived factors of intelligence in STEM education?

11.2 How We Tried to Answer the Questions

Each research question was attended to through an individual study with each having its own unique method and with much of the data collection being completed in Ireland. RQ1 was conceived with the view that technology subjects have unique characteristics to other STEM areas due to their applied nature and the presence of technological knowledge (Buckley et al., 2019a). To explore this from a performance perspective, longitudinal data of Leaving Certificate performance in Ireland was collected from five schools over a five-year period ($n = 1761$). The Leaving Certificate is a state examination which is taken at the end of post-primary education in Ireland, it serves as the primary matriculation system to third level education, and exams are designed and administered by an independent body, the State Examinations Commission. This data was explored to see the relationship between overall performance in the Learning Certificate relative to studying the technology subjects or the sciences which are optional in the Irish system. Further, it was examined to see the impact of studying a single versus multiple technology subjects. Differences in performance as a result of subject choice served as an indication for variance in subject context.

RQ2 sought to investigate if having a high level of spatial ability was related to performance in technology education. Viewing graphics as a common language within the technologies (Baynes, 2017; Danos, 2017) and to eliminate the potential influence of discipline knowledge, undergraduate students ($n = 215$) in an initial technology teacher education programme completed a series of geometric problems and psychometric tests of spatial ability (Buckley et al., 2019c). The solutions for the problems, both in terms of performance and approach taken, were examined relative to the students' levels of spatial ability.

To address RQ3, which sought to determine the current state of knowledge with respect to the relationship between spatial ability and STEM, a narrative literature review was conducted (Buckley et al., 2018a). The aim of this was to present a working definition for spatial ability in terms of individual cognitive factors, i.e. to describe comprehensively the various components of spatial ability such as the ability to mentally rotate geometries and to accurately imagine geometries from alternative perspectives. In addition, understanding the various components of spatial ability would permit a more accurate review of how it relates to STEM education.

RQ4 and RQ5 were very much related in that RQ4 aimed to determine the implicit understanding of intelligence in terms of different intellectual factors held by undergraduate technology teacher education students and RQ5 then explored explicit relationships between these factors. The participants were selected because they had a unique perspective of being students of technology education, engaging with contemporary perspectives on technology education, and regularly interacting with academics in the field through their studies. A survey method was used to address RQ4 whereby volunteering students ($n = 205$) were first asked to list the components they believed contributed to intelligence in STEM and after this, once the responses were compiled, volunteering students from the same population ($n = 213$) were asked to rate how important each component was to their own conception of intelligence in STEM. The analysis then resulted in a model which depicted the factors of intelligence thought to be most important for describing intelligence in STEM from the perspective of Irish undergraduate technology education students and their relative weightings of perceived importance (Buckley et al., 2019b). These results and the findings in relation to RQ3 were then used to design a method to address RQ5 (Buckley et al., 2018c). Two studies were employed for this which involved psychometric indicators for various factors of intelligence based on empirical frameworks (Schneider & McGrew, 2018) and the results of the previously described work being administered to a similar sample of undergraduate technology teacher education students. In the first study, a sample of volunteering students ($n = 85$) were administered 17 psychometric tests so that various factors of intelligence could be explored to determine their relationship with fluid intelligence, the closest factor of intelligence to general intelligence (Ebisch et al., 2012). In the second study, the factors of intelligence which had a significant relationship with fluid intelligence in the first study were explored again with a new sample of volunteering students ($n = 87$) and additional psychometric tests in a conceptual replication. This resulted in a model which described, in the context of intelligence, why spatial ability could be contributing to academic performance in STEM education, and more specifically in technology education.

11.3 What Was Found Out

Much research relating spatial ability to STEM does not take technology education into account and instead focusses on science, mathematics, and engineering. While there are many parallels between STEM areas, technology education does have qualitatively unique characteristics such as the treatment of design and prevalence of provisional knowledge application. There were several results which related specifically to this in the first study which explored student performance in the Leaving Certificate in Ireland. The total points in the Leaving Certificate for each student were calculated and they were then divided into quartiles, i.e. quartile 1 (Q1) described the poorest performing 25% of students overall and quartile 4 (Q4) described the highest performing 25% of students overall. The relationships between enrolment within the four technology subjects (Design and Communication Graphics [DCG], Construction Studies, Engineering, and Technology) and being in different quartiles were all statistically significant, and interestingly, students who studied the technologies and more applied subjects such as Art and Home Economics were less likely to be in the top 25% of students based on overall performance than those who chose to study less applied subjects such as Mathematics, modern languages and the natural sciences (Fig. 11.1). Further, the more technology subjects a student studied the more likely they were to find themselves in the lowest quartile overall. Finally, it was found that student performance in their technology subjects, whether they studied one, two or three of them, was generally greater than their average performance across all their other subjects. It should be noted that all students would typically study Mathematics, English and Irish as most schools offer these as compulsory subjects. Based on the results of this study, it was inferred that there was a general systematic advantage to studying subjects which were more closely aligned with these compulsory subjects, i.e. subjects with a greater emphasis on knowledge acquisition and a systematic disadvantage to enrolling in optional subjects which placed a greater emphasis on knowledge application. This of course does not reflect student variables which could see the reverse true on an individual level. The distinction, albeit along a continuum, from more to less application within a subject area provides evidence

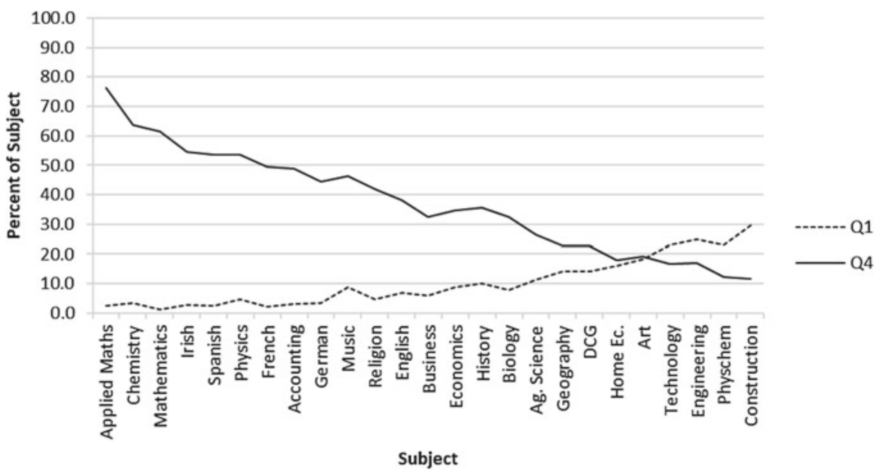

Fig. 11.1 Statistically significant distributions between Q1 and Q4 for Higher level subjects. Subjects are ordered (left to right) based on the variance between the percentage of students in Q1 and Q4 from Buckley and Seery (2018)

that the qualitative differences in context between technology and other STEM areas position technology as a unique subject in which to explore individual differences in intelligence.

The second study looked more specifically at how spatial ability, as measured across paper and pencil psychometric tests, related to performance in technology education problems. In Ireland at least, graphics can be viewed as a common element across the technology subjects, so it was selected for the case study. Also, task related knowledge can influence performance (Hambrick et al., 2012) so, it was considered useful to explore performance in a graphical problem where discipline knowledge, other than what was necessary to interpret the geometries, was not necessary. What was of particularly interest here was whether having a higher level of spatial ability correlated with increased performance in the problems. Taking one problem from within a variety of problems for an in-depth analysis (Fig. 11.2) students were divided into quartiles, however this time it was based on their level of spatial ability. It was observed that students with higher levels of spatial ability performed better on the graphical task. This provided the first insight that spatial ability could be related to performance in at least certain aspects of technology education. Further to this, of particular interest was how students with varying levels of spatial ability engaged with the problem. To aid themselves in solving the problem, students used strategies such as creating separate isometric sketches of the dice, indexing, or labelling the vertices of the cube, editing the provided development in ways to make mapping the dice detail easier, adding hidden detail to the orthographic views, converting the dice detail to numeric digits and adding additional orthographic detail. The most used strategies were to create an additional isometric sketch and index the cube vertices, and it was found that students who had lower levels of spatial ability used these strategies more frequently than those with higher levels of spatial ability. It is possible that these strategies were applied to augment their lower spatial skills, and therefore any progression of investigations on the association between spatial ability and technology education performance needs to take forms of potential external thinking into account.

The third study involved completing a narrative literature review of spatial ability research. Since its inception by Galton, spatial ability has been recognised as comprising of multiple components or factors (Galton, 1879a, b, 1880, 1881). Over time, knowledge of these factors has been refined (Carroll, 1993; Lohman, 1979; Schneider & McGrew, 2012) and in current frameworks spatial ability is described as having 11 factors (Schneider & McGrew, 2012). Examples of these include the *visualisation* factor which is described as "the ability to perceive complex patterns and mentally simulate how they might look when transformed (e.g. rotated, changes in size, partially obscured)", the *imagery* factor which is described as "the ability to mentally produce very vivid images", and the *speeded rotations* factor which is described as "the ability to solve problems quickly by using mental rotation of simple images" (Schneider & McGrew, 2012, pp. 129–130). The implication for this is that by saying spatial ability is related to STEM outcomes, there is a degree of uncertainty as to what factor of spatial ability is being described. In practice, the most accurate way to describe spatial ability is relative to the instruments used to measure

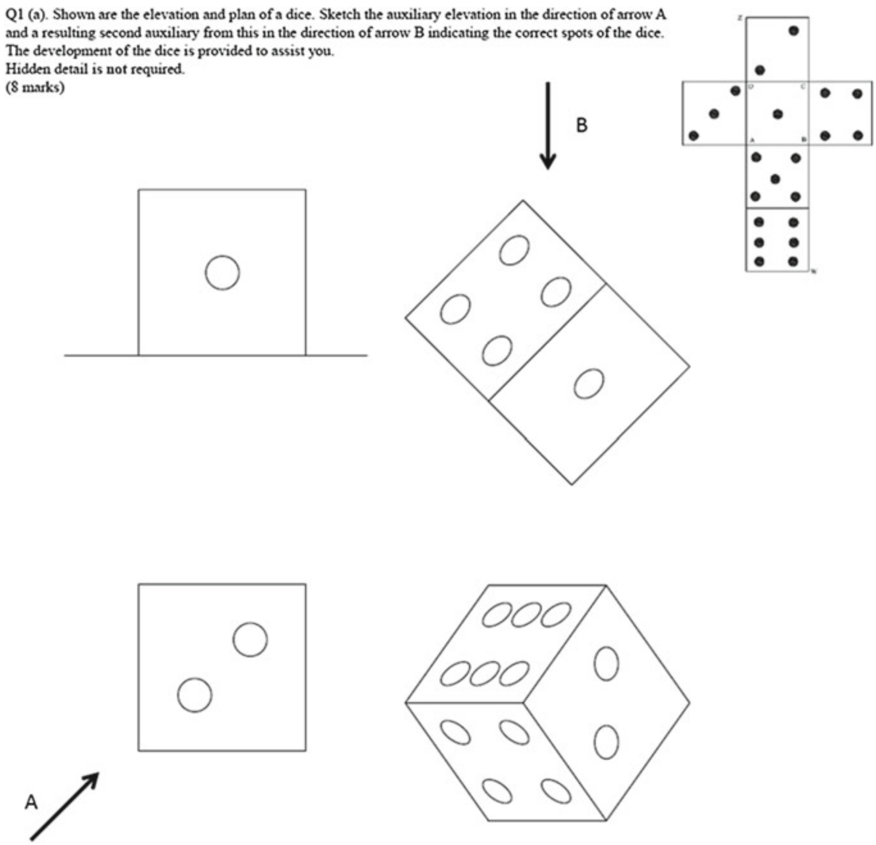

Fig. 11.2 Solution to graphical problem posed to participants. The solution required producing the first and second auxiliary views in the directions of arrows A and B, respectively. Performance was evaluated based on correct orientation of the cube and positioning of the dice detail, not on quality of the presentation

it (Meehl, 2006) but there was a need for a more comprehensive working definition and framework to guide the progression of this work.

The narrative review revealed many more spatial factors than are described in current frameworks (Buckley et al., 2018a). This was largely a result of technological advances leading to new possibilities for computerised testing of dynamic spatial factors, i.e. moving stimuli not possible in paper and pencil tests. It also revealed that the visualisation factor, which is the strongest indicator of a general spatial ability (Carroll, 1993) and describes the ability to mentally manipulate complex geometries, is the factor with most evidence underpinning a relationship with STEM outcomes. This suggests that other factors may also be related but there is a lack of evidence for this and makes it clearer what is being described by the term spatial ability.

The fourth study then progressed to asking what, from the perspective of Irish technology teacher education students, broadly describes intelligence in STEM. It was of interest to determine whether spatial ability was part of this implicit theory. The result of the survey method was a model indicating that intelligence in STEM was viewed as comprising of three factors, a social competence which had the weakest loading on the student's overall conception of intelligence, a general competence, and a technological competence which had the highest loading on their overall conception of intelligence (Fig. 11.3).

The technological competence factor was of particular interest as it further strengthens the inference made from the first study that technology education provides a unique context for exploring spatial ability in STEM education. Its interpretation is akin to the concept of technacy, defined as "the ability to understand, communicate and exploit the characteristics of technology to discern how human technological practice is necessarily a holistic engagement with the world that involves people, tools and the consumed environment, driven by purpose and contextual considerations" (Seemann, 2009, pp. 117–118). Within this factor, spatial ability was deemed to be an important descriptor of STEM intelligence giving validity

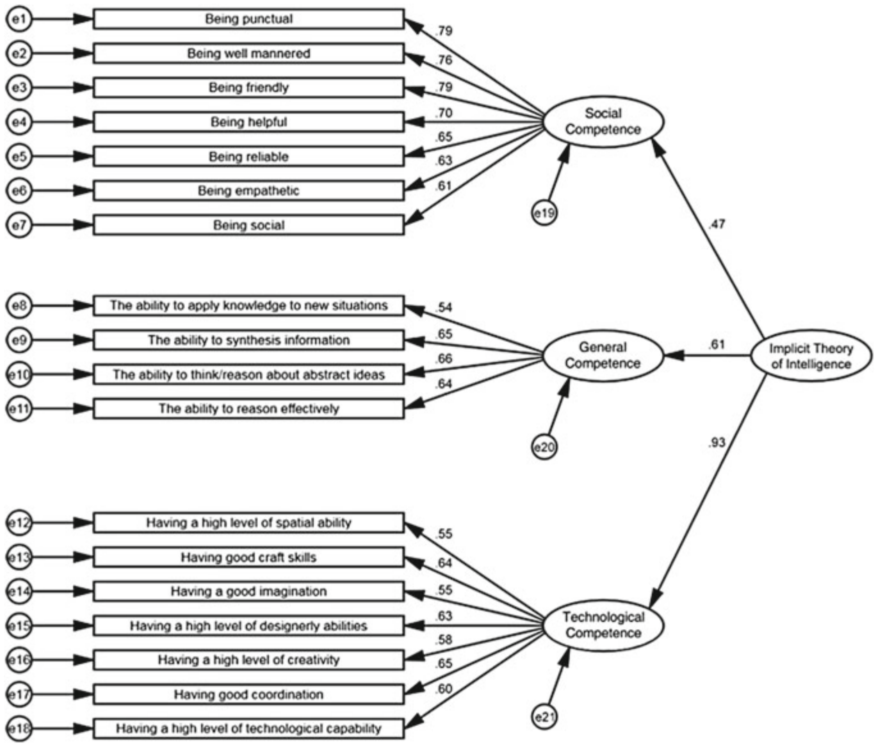

Fig. 11.3 Implicit theory of STEM intelligence from Irish undergraduate technology teacher education students (Buckley et al., 2019b)

for examining the relationship between spatial ability and intelligence in this context explicitly. What was arguably most interesting was the lack of indication that a degree of discipline knowledge was viewed as contributing to an intelligent person in this context. This of course does not mean that the students did not view discipline knowledge as important, just that it was not a perceived descriptor of an intelligent person in STEM. A prominent theory of intelligence is the theory of fluid and crystallised intelligence (Horn & Cattell, 1966). In this theory, the construct of a single general intelligence is conceived as comprising of two dimensions, fluid intelligence which relates to novel problem solving and crystallised intelligence which reflects acquired knowledge. As no evidence was found that a factor similar to crystallised intelligence described intelligence but the general competence factor aligned with fluid intelligence, only fluid intelligence was considered with respect to general intelligence in the fifth study which sought to examine relationships between a variety of specific factors and intelligence explicitly.

Where the fourth study explored undergraduate technology teacher education students' implicit theories of intelligence, the fifth study investigated intelligence in this population explicitly (Buckley et al., 2018c). A sample of these students were administered psychometric tests for 16 specific factors of intelligence such as the visualisation factor, and for the broad factor of fluid intelligence. Of the 16 specific factors, 9 were spatial factors based on the narrative review in the third study, with the others associated with factors of long-term memory, short-term memory, processing speed, and general reasoning. A regression analysis indicated that visualisation, inductive reasoning, and memory span were predictive of fluid intelligence, and this was then found to replicate in a second study. This result presents a causal theory for how spatial ability could relate to STEM performance. Fluid intelligence has general educational significance (Lohman, 1996) as it has been identified as a causal factor in learning as it supports the acquisition of knowledge (Kvist & Gustafsson, 2008; Primi et al., 2010). Memory span affords the capacity to retrieve and hold chunks of information in the working memory while engaging with a problem or task. Visualisation enables this information to be generated, represented, and manipulated. Finally, inductive reasoning allows for students to draw inferences based on the available information. It is possible that if technology education were not the context for this research and instead an area of STEM with a greater emphasis on knowledge acquisition was used that fluid intelligence would not have been presented as a mechanism for the association between spatial ability and STEM performance. However, the result of this is now a testable theory for exploring the impact of spatial ability in technology, and more broadly in STEM education.

11.4 How This Might Be Used to Improve Teaching and Learning

11.4.1 Situating the Research Within Technology Education

There are several ways in which the results of this work could be used to improve teaching and learning in technology education and more broadly in STEM fields. First though, it is important to remember that to date there has been a lack of research in technology education relating to intelligence and spatial ability so there is need for more research in this space to better inform associated educational change (cf. Buckley, 2020 for an extended discussion). Spatial ability was a consistent focus of this research; however, the context of technology education is an important dimension. Research clearly illustrates a link between spatial ability and discipline knowledge (Hambrick et al., 2012; Uttal & Cohen, 2012), and technological knowledge and its treatment have specific qualities which highlight the importance of spatial ability for technology students. For a comprehensive description of technological knowledge from a philosophical perspective, readers are encouraged to read de Vries' (2016) *Teaching about Technology*. However, one characteristic of the treatment of technological knowledge which is critical to this discussion is noted by Kimbell (2011) when he says:

> What we do is formulate a view of knowing that empowers learners to take action with *provisional* knowledge – and that encourages them to refine and deepen that knowledge in response to the demands of the task. So, we have deliberately transposed the issue of 'knowing' stuff into the business of 'finding-out-about' stuff (p. 7).

Students in technology education, particularly due to the inclusion of design and regular engagement with novel problems (cf. Buckley et al., 2020 for an extended discussion) must frequently acquire knowledge which may only have relevance to a specific problem at hand and for a short period of time. This may be the reason the survey methodology used in response to the fourth research question, a discipline knowledge factor was not viewed by undergraduate technology teacher education students as a defining characteristic of intelligence in STEM. This relationship with knowledge is being highlighted here with the intention that readers maintain this idea as they continue through the discussion. As an aside, in Buckley et al. (2019a) there is an extended discussion about technological knowledge from a policy perspective where the inclusion of technology curricula as a core part of all post-primary students' educational experience is advocated for. Such policy decisions are a critical aspect of teaching and learning. This space, however, will be used to consider the implications of the work in this thesis specifically within a technology classroom in the context of pedagogy.

11.4.2 Policy Recommendation

With respect to spatial ability, at least in Ireland within the post-primary subjects of Graphics (lower secondary level) and Design and Communication Graphics (upper secondary level), subject level aims include the development of visualisation. From the literature review conducted, visualisation can be understood as one of many factors of spatial ability, however it is the factor which has the most empirical evidence linking it with desirable educational outcomes. For the broader remit of technology curricula internationally, alongside discipline goals such as the development of technological capability and/or technological literacy and general goals such as the development of numeracy and literacy, it would be of value for policy to reflect the aspiration to positively affect spatial ability. Reasons for this include (1) the association between higher levels of spatial ability and increased STEM performance and retention generally (Sorby et al., 2018; Wai et al., 2009), (2) the relationship between spatial ability and fluid intelligence, as shown in the fifth study within this body of work, which is associated with learning in general (Kvist & Gustafsson, 2008; Primi et al., 2010), and (3) as fluid intelligence is the closest, i.e. strongest correlating, factor of intelligence to general intelligence (Ebisch et al., 2012), the development of spatial ability may lead to some positive outcomes that are associated with higher levels of general intelligence. These include benefits to mental health, conscientiousness, happiness, risk perception and living longer (Ritchie, 2015). The links between spatial ability and knowledge acquisition should be seen as paramount here when reflecting on the need for technology students to find out about stuff often quickly in the context of a problem. Higher levels of spatial ability could support technology students to a great extent in negotiating the provisional knowledge described by Kimbell (2011), and, by regularly engaging with novel problems, technology students will often find themselves as novices with respect to the problem they are trying to solve. Higher levels of spatial ability are of greater benefit to students who are more novice relative to a specific educational task than to students who are more expert. Also, while the link between spatial ability and outcomes associated with general intelligence is speculative (but would be an interesting research avenue), it is inherently good to develop students' cognitive faculties as doing so facilities more complex thought. The question then becomes how this could be achieved in practice.

11.4.3 Approaches to Developing Spatial Ability in the Classroom

One of the aspects that makes spatial ability research so translatable to educational practice is that the related evidence indicates that it can be developed through targeted interventions (Uttal et al., 2013). At post-primary level, the intervention developed by Sorby has been shown to be successful by leading to increased STEM educational performance and retention on numerous occasions over the last two decades (Sorby et al., 2018). This presents an opportunity for educators to implement this intervention directly. In practice, this intervention is designed to be delivered over ten two-hour sessions, one session per week over ten weeks, where students engage with activities specifically designed to develop spatial ability. That said, the use of such an intervention is not always possible. Two inhibitors from the perspective of schools and teachers could be cost implications and time constraints. Recognising these, a second approach to developing spatial ability in classrooms is through what has been termed "spatialising the curriculum". The idea behind this is, rather than adding to an existing curriculum, to consider how the development of spatial ability could be integrated into pedagogical activities while students are engaging with curriculum defined discipline knowledge/learning outcomes. Newcombe (2017) describes a number of such activities which teachers could adopt and engage their students in including the use of symbolic systems such as maps, diagrams, graphs and in descriptive language, the use of analogy, and incorporating an action-to-abstraction process through students' movement, gesturing and sketching. Undoubtedly, all technology teachers will see where these types of activities can be incorporated into their practice, and many do so already. For example, sketching is a common activity in technology classrooms, students regularly iterate between 2- and 3-dimensional representations of objects, and the prevalence of modelling provides substantial opportunity for taking concrete objects and thinking about them as abstractions as elements are considered in alternative contexts. That said, it is worth thinking specifically about the technology classroom in the context of a hypothetical case study to reflect on meaningful use of such pedagogies and an important caveat.

By way of example, the use of computer aided design (CAD) is quite common in technology education. CAD expertise has been associated with spatial ability (Chester, 2007), CAD modelling behaviours have been explicitly explored in technology education (Buckley et al., 2018b; Buckley & Seery, 2018), and CAD use has been investigated with respect to developing spatial ability (Yue & Chen, 2001). Considering how CAD is used is critical, and here CAD is serving as an analogy for any modelling activity which could support students visualising an idea such as sketching or making a physical model. The use of CAD has the capacity to both supplement a student in visualising a thought or idea and prevent the need for a student to mentally generate an image as the technology can do this for them. Therefore, it could be either aiding the development of spatial ability or inhibiting it. From a pedagogical perspective, and the results of Buckley et al. (2019c) on geometric problem solving behaviours support this, technology teachers should think about activities which can spatialise the curriculum both as scaffolds for developing spatial ability but also their potential to mitigate the need for this type of cognitive activity. Achieving this balance is not easy, especially within curricula that also require students to develop modelling expertise. What could work, and the idea of "could" in this instance will be discussed more in the conclusion of this chapter with respect to potential for action research, is the development of pedagogical approaches wherein students transition from modelling activities where their idea is less realised to more realised. The model provided by Johnston-Wilder and Mason (2005) could be greatly beneficial here (Fig. 11.4). For example, students could begin by discussing

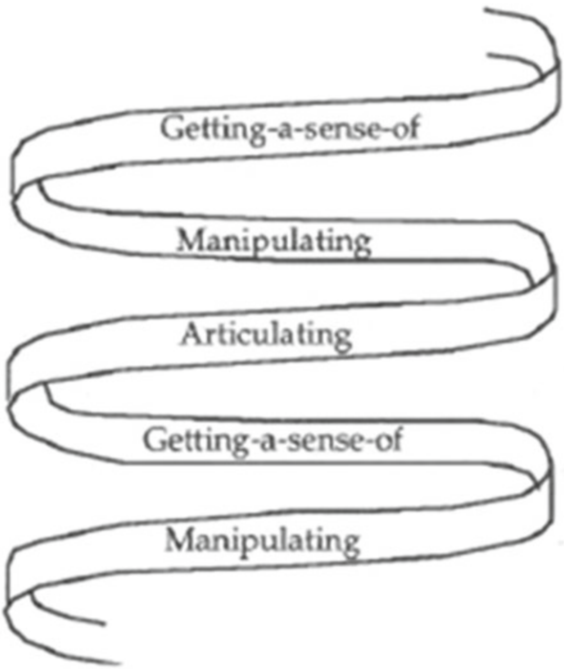

Fig. 11.4 Model for effecting learning (Johnston-Wilder & Mason, 2005)

their ideas with peers (getting a sense of the idea), move onto sketching their ideas and then creating physical models (manipulating their ideas), and finally creating an accurate CAD model (articulating their ideas). This process would see students having to visualise their thinking prior to working with CAD where the function of using CAD in this instance could be to both develop modelling proficiency and to present an accurate representation of their design.

11.5 Conclusion

There are two important applied research questions which are of immediate interest to progressing spatial ability research in technology education. The first of these is best described using examples of recently published research. As previously noted, at least in Ireland, post-primary graphics education has a specific agenda to develop students' visualisation, an agenda which we would recommend be extended to technology subjects more generally. In a study by Prieto and Velasco (2010), the authors concluded that studying technical drawing resulted in the development of visualisation. However, a recent study by Contreras et al. (2018) found that visualisation improved both with and without studying technical drawing. By not including a control group to compare with, it appears that Prieto and Velasco (2010) observed natural development of visualisation in students from educational engagement rather than a specific effect of studying technical drawing. However, the method used by Contreras et al. (2018), which did involve a control group (who were enrolled in a mathematics course), involved a single sample of architecture students (studying technical drawing) being compared to mathematics students. It is therefore possible that some of the previously described school variables (such as class size, teacher quality, etc.) impacted the results. A recommendation for future research would be to conduct a study whereby students studying graphics (or technology) from multiple schools (to reduce potential school variable effects) are compared with a control group consisting of students, again from multiple schools, not studying graphics/technology to see if there was an effect of graphics/technology education on the development of visualisation.

The second important research question relates to research which could be conducted within individual classrooms. As discussed, there is a need to understand how modelling relates to spatial ability development. There are two facets to this from a technology classroom standpoint. First, it would be of interest for teachers to investigate if certain modelling tools and techniques, i.e. CAD, sketching, having conversations with peers, making physical models, etc., which are accessible to teachers promote the development of spatial ability or inhibit its development. The pedagogical ordering of events is relevant for this with an example of a meaningful research question being whether requiring students to sketch their ideas before beginning CAD modelling improves spatial ability more than using CAD alone. The second aspect to this would be an extension, whereby modelling proficiency is considered. Taking CAD as an example for continuity (but again using it as an analogy for all modelling methods), it would be interesting to see if there is a difference in the use of CAD for the development of spatial ability between students with a high level of CAD proficiency compared to those with a low level of proficiency. One hypothesis could be that higher CAD proficiency supports spatial development as students are not negatively impacted by inability to use the technology. An alternative hypothesis could be that by having less CAD proficiency, more attention is required for the activity as a whole for students to accurately create a model and so therefore must better understand their model. Similarly, CAD modelling may have different effects on students with higher or lower levels of spatial ability. This line of research has the added value of comparing specific activities which can be more controlled than comparisons of whole subject effects, allowing for greater capacity to identify causal variables which can then be translated into policy and practice recommendations.

To conclude, the central theme which can be used to develop related action research projects for contributing to the current body of knowledge pertaining to the role of spatial ability in technology education is to determine what works, when and for whom.

References

Atit, K., Uttal, D., & Stieff, M. (2020). Situating space: Using a discipline-focused lens to examine spatial thinking skills. *Cognitive Research: Principles and Implications, 5*(19), 1–16. https://doi.org/10.1186/s41235-020-00210-z

Baynes, K. (2017). Meaning without words. In E. Norman & K. Baynes (Eds.), *Design epistemology and curriculum planning* (pp. 47–63). Loughborough Design Press.

Buckley, J. (2020). The need to consider the predictive capacity of intelligence and its malleability within design and technology education research. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-020-09588-9

Buckley, J., Seery, N., & Canty, D. (2018). A heuristic framework of spatial ability: A review and synthesis of spatial factor literature to support its translation into STEM education. *Educational Psychology Review, 30*(3), 947–972. https://doi.org/10.1007/s10648-018-9432-z

Buckley, J., Seery, N., & Canty, D. (2018). Heuristics and CAD modelling: An examination of student behaviour during problem solving episodes within CAD modelling activities. *International Journal of Technology and Design Education, 28*(4), 939–956. https://doi.org/10.1007/s10798-017-9423-2

Buckley, J., Seery, N., Canty, D., & Gumaelius, L. (2018). Visualization, inductive reasoning, and memory span as components of fluid intelligence: Implications for technology education. *International Journal of Educational Research, 90*(1), 64–77. https://doi.org/10.1016/j.ijer.2018.05.007

Buckley, J., Seery, N., Power, J., & Phelan, J. (2019). The importance of supporting technological knowledge in post-primary education: A cohort study. *Research in Science & Technological Education, 37*(1), 36–53. https://doi.org/10.1080/02635143.2018.1463981

Buckley, J., O'Connor, A., Seery, N., Hyland, T., & Canty, D. (2019). Implicit theories of intelligence in STEM education: Perspectives through the lens of technology education students. *International Journal of Technology and Design Education, 29*(1), 75–106. https://doi.org/10.1007/s10798-017-9438-8

Buckley, J., Seery, N., & Canty, D. (2019). Investigating the use of spatial reasoning strategies in geometric problem solving. *International Journal of Technology and Design Education, 29*(2), 341–362. https://doi.org/10.1007/s10798-018-9446-3

Buckley, J., Seery, N., Gumaelius, L., Canty, D., Doyle, A., & Pears, A. (2020). Framing the constructive alignment of design within technology subjects in general education. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-020-09585-y

Buckley, J., & Seery, N. (2018). Balancing curriculum intent with expected student responses to designerly tasks. *Design and Technology Education: An International Journal*, *23*(1), 26–39. https://ojs.lboro.ac.uk/DATE/article/view/2302

Carroll, J. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge University Press.

Cheng, Y., & Mix, K. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development, 15*(1), 2–11. https://doi.org/10.1080/15248372.2012.725186

Chester, I. (2007). Teaching for CAD expertise. *International Journal of Technology and Design Education, 17*(1), 23–35. https://doi.org/10.1007/s10798-006-9015-z

Contreras, M. J., Escrig, R., Prieto, G., & Elosúa, M. R. (2018). Spatial visualization ability improves with and without studying technical drawing. *Cognitive Processing, 19*(3), 387–397. https://doi.org/10.1007/s10339-018-0859-4

Danos, X. (2017). Graphicacy and a taxonomy. In E. Norman & K. Baynes (Eds.), *Design epistemology and curriculum planning* (pp. 64–84). Loughborough Design Press.

Detterman, D. (2016). Education and intelligence: Pity the poor teacher because student characteristics are more significant than teachers or schools. *The Spanish Journal of Psychology, 19*(e93), 1–11. https://doi.org/10.1017/sjp.2016.88

Ebisch, S., Perrucci, M., Mercuri, P., Romanelli, R., Mantini, D., Romani, G. L., Colom, R., & Saggino, A. (2012). Common and unique neuro-functional basis of induction, visualization, and

spatial relationships as cognitive components of fluid intelligence. *NeuroImage, 62*(1), 331–342. https://doi.org/10.1016/j.neuroimage.2012.04.053
Galton, F. (1879). Generic images. *Proceedings of the Royal Institution, 9*(1), 161–170.
Galton, F. (1879b). Generic images. *The Nineteenth Century*, *6*(1), 157–169
Galton, F. (1880). Mental imagery. *Fortnightly Review*, *28*(1), 312–324
Galton, F. (1881). Visualised numerals. *Nature, 21*(1), 85–102.
Gaughran, W. (2002). Cognitive modelling for engineers. In *2002 American society for engineering education annual conference and exposition.*
Hambrick, D., Libarkin, J., Petcovic, H., Baker, K., Elkins, J., Callahan, C., Turner, S., Rench, T., & LaDue, N. (2012). A test of the circumvention-of-limits hypothesis in scientific problem solving: The case of geological bedrock mapping. *Journal of Experimental Psychology: General, 141*(3), 397–403. https://doi.org/10.1037/a0025927
Horn, J., & Cattell, R. (1966). Refinement and test of the theory of fluid and crystallized general intelligences. *Journal of Educational Psychology, 57*(5), 253–270. https://doi.org/10.1037/h0023816
Hyland, T., Buckley, J., Seery, N., Power, J., & Gordon, S. (2018). Investigating the relationships between spatial ability, interest, and task experience on knowledge retention in engineering education. In N. Seery, J. Buckley, D. Canty, & J. Phelan (Eds.), *PATT2018: Research and practice in technology education: Perspectives on human capacity and development* (pp. 263–269). PATT. https://www.iteea.org/File.aspx?id=157698&v=611c2ad1%0A
Hyland, T., Buckley, J., Seery, N., & Gordon, S. (2019). The predictive capacity of spatial ability for knowledge retention in third level technology and engineering education. In S. Pule & M. de Vries (Eds.), *PATT2019: Developing a knowledge economy through technology and engineering education* (pp. 213–220). PATT. https://www.iteea.org/File.aspx?id=157700&v=e94e5d51%0A
Johnston-Wilder, S., & Mason, J. (2005). *Developing thinking in geometry*. SAGE Publications.
Jones, S., & Burnett, G. (2008). Spatial ability and learning to program. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environments*, *4*(1), 47–61. https://doi.org/10.17011/ht/urn.200804151352
Khoza, S. (2017). Difficulties in teaching and learning sectional drawing in a university based in the Eastern Cape, South Africa. In P. J. Williams & D. Barlex (Eds.), *Contemporary research in technology education: Helping teachers develop research-informed practice* (pp. 89–103). Springer.
Kimbell, R. (2011). Wrong ... but right enough. *Design and Technology Education: An International Journal*, *16*(2), 6–7. https://ojs.lboro.ac.uk/DATE/article/view/1620
Kozhevnikov, M., Motes, M., & Hegarty, M. (2007). Spatial visualization in physics problem solving. *Cognitive Science, 31*(4), 549–579. https://doi.org/10.1080/15326900701399897
Kvist, A., & Gustafsson, J.-E. (2008). The relation between fluid intelligence and the general factor as a function of cultural background: A test of cattell's investment theory. *Intelligence, 36*(5), 422–436. https://doi.org/10.1016/j.intell.2007.08.004
Lin, H. (2016). Influence of design training and spatial solution strategies on spatial ability performance. *International Journal of Technology and Design Education, 2016*(1), 123–131. https://doi.org/10.1007/s10798-015-9302-7
Lohman, D. (1996). Spatial ability and g. In I. Dennin & P. Tapsfield (Eds.), *Human abilities: Their nature and measurement* (pp. 97–116). Lawrence Erlbaum Associates.
Lohman, D. (1979). *Spatial ability: A review and reanalysis of the correlational literature*. Office of Naval Research.
Meehl, P. (2006). The power of quantitative thinking. In N. Waller, L. Yonce, W. Grove, D. Faust, & M. Lenzenweger (Eds.), *A Paul Meehl reader: Essays on the practice of scientific psychology* (pp. 433–444). Erlbaum.
Newcombe, N. (2017). *Harnessing spatial thinking to support STEM learning. OECD Education Working Papers, No. 161*. OECD.

O'Connell, M. (2018). The power of cognitive ability in explaining educational test performance, relative to other ostensible contenders. *Intelligence, 66*(1), 122–127. https://doi.org/10.1016/j.intell.2017.11.011

Owen, A., Hampshire, A., Grahn, J., Stenton, R., Dajani, S., Burns, A., Howard, R., & Ballard, C. (2010). Putting brain training to the test. *Nature, 465*(7299), 775–778. https://doi.org/10.1038/nature09042

Prieto, G., & Velasco, A. (2010). Does spatial visualization ability improve after studying technical drawing? *Quality and Quantity, 44*(5), 1015–1024. https://doi.org/10.1007/s11135-009-9252-9

Primi, R., Ferrão, M. E., & Almeida, L. (2010). Fluid intelligence as a predictor of learning: A longitudinal multilevel approach applied to math. *Learning and Individual Differences, 20*(5), 446–451. https://doi.org/10.1016/j.lindif.2010.05.001

Ritchie, S. (2015). *Intelligence: All that matters*. John Murray Learning.

Schneider, J., & McGrew, K. (2012). The Cattell-Horn-Carroll model of intelligence. In Dawn Flanagan & P. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (3rd edn, pp. 99–144). Guilford Press.

Schneider, J., & McGrew, K. (2018). The Cattell-Horn-Carroll theory of cognitive abilities. In D. Flanagan & E. McDonough (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 73–163). The Guilford Press.

Seemann, K. (2009). Technacy education: Understanding cross-cultural technological practice. In J. Fien, R. Maclean, & M.-G. Park (Eds.), *Work, learning and sustainable development: Opportunities and challenges* (pp. 117–132). Springer.

Simons, D., Boot, W., Charness, N., Gathercole, S., Chabris, C., Hambrick, D., & Stine-Morrow, E. (2016). Do "brain-training" programs work? *Psychological Science in the Public Interest, Supplement, 17*(3), 103–186. https://doi.org/10.1177/1529100616661983

Smith-Woolley, E., Pingault, J.-B., Selzam, S., Rimfeld, K., Krapohl, E., von Stumm, S., Asbury, K., Dale, P., Young, T., Allen, R., Kovas, Y., & Plomin, R. (2018). Differences in exam performance between pupils attending selective and non-selective schools mirror the genetic differences between them. *NPJ Science of Learning, 3*(3), 1–7. https://doi.org/10.1038/s41539-018-0019-8

Sorby, S., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences, 26*(1), 20–29. https://doi.org/10.1016/j.lindif.2013.03.010

Sorby, S., Veurink, N., & Streiner, S. (2018). Does spatial skills instruction improve STEM outcomes? The answer is "yes." *Learning and Individual Differences, 67*(1), 209–222. https://doi.org/10.1016/j.lindif.2018.09.001

Uttal, D., & Cohen, C. (2012). Spatial thinking and STEM education: When, why, and how? *Psychology of Learning and Motivation, 57*(1), 147–181. https://doi.org/10.1016/B978-0-12-394293-7.00004-20

Uttal, D., Meadow, N., Tipton, E., Hand, L., Alden, A., Warren, C., & Newcombe, N. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352–402. https://doi.org/10.1037/a0028446

de Vries, M. (2016). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*. Springer.

Wai, J., Lubinski, D., & Benbow, C. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835. https://doi.org/10.1037/a0016127

Yue, J., & Chen, D. (2001). Does CAD improve spatial visualization ability? In M. Tatu (Ed.), *2001 American society for engineering education annual conference and exposition* (pp. 6.394.1–6.394.8). ASEE.

Jeffrey Buckley is a Lecturer in Research Pedagogy at Technological University of the Shannon: Midlands Midwest, Ireland, and a Researcher in engineering education at KTH, Royal Institute

of Technology, Sweden. He is a member of the Technology Education Research Group and Engineering Education in Society research group. Jeffrey received his PhD from KTH in 2018 in the area of spatial ability and learning in technology education. His current research interests include the relationship between spatial ability and learning, diversity and inclusivity in engineering education, and methods and practices in technology and engineering education research.

Niall Seery is currently the Chair of Technological Education at Technological University of the Shannon: Midlands Midwest. Niall has a background in technology teacher education, where he spent 20 years as an academic with a specialist interest in pedagogical practice. In 2010, Niall founded and continues to direct the Technology Education Research Group, where he is still active in research supervision and mentorship. Niall also served as a visiting associate professor of technology education at KTH, Royal Institute of Technology, Stockholm. He remains committed to advocating for Technology and Engineering education research and supporting the development of associated policy and practice.

Donal Canty is a qualified post-primary teacher with 8 years' classroom experience. Donal's research interests are in the areas of pedagogy and assessment with particular interest in utilising comparative judgment to enhance student learning and capability. Donal is one of the founding members of the Technology Education Research Group (TERG) and has led both national and international research projects. Donal has extensive experience of programme design for both secondary and higher education and is currently a lecturer in the School of Education at the University of Limerick.

Lena Gumaelius is the Pro Vice-Chancellor at Mälardalens Högskola (MDH) where her main responsibility is education. Besides her duties at MDH, she works as an associate professor in engineering education at KTH, Royal Institute of Technology, Sweden, where she is leading the Engineering Education in Society research group. Her main research interest is in engineering and technology education, where she focuses on inclusiveness and attractiveness as well as education for sustainable development.

Part IV
Curriculum and Pedagogy

Chapter 12
Appropriate Use of 'Assessment for Learning' Practices to Enhance Teaching and Learning

Chandan Boodhoo

Abstract 'Assessment for learning', characterised as a process where the teacher and students work in partnership, focusses on providing qualitative insights into students' understanding (Warwick et al. in Curric J 26:39–69, 2015) and is key to establish effective teaching and students' learning. Since little exploration has been conducted in assessment in technology education, as identified by Williams (Proceedings of the 9th Biennial international conference on technology education. Griffith University, pp 269–275, 2016) and (Hartell et al. in Int J Technol Des Educ 25:321–337, 2015), this research investigated Design and Technology teachers' 'assessment for learning' practices in secondary schools. For example, several research studies suggest that teachers need to identify and plan both specific and overall technology learning outcomes to improve students' learning (Cowie et al. in More than talk and writing: exploring the multimodal nature of classroom interactions. University of Waikato Research Commons, 2008; Jones and Moreland in Int J Technol Des Educ 14:121–140, 2004; Moreland et al. Des Technol Educ Int J 12(2):37–48., 2007). The participants involved were 29 Design and Technology teachers from 11 schools in Mauritius. This research's findings indicate that Design and Technology teachers did not effectively enact 'assessment for learning' strategies to improve their teaching and students' learning. This research suggests several approaches to improve teaching, assessment, and learning in Design and Technology.

Keywords Assessment for learning · Design and technology · Technology education · Teaching and learning

C. Boodhoo (✉)
Mauritius Institute of Education, Reduit, Mauritius
e-mail: c.boodhoo@mie.ac.mu

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_12

12.1 The Questions Asked and Why They Are Important

Assessment significantly influences what students learn, how they learn, how much they learn, and how effectively they learn (Jimaa, 2011). Research shows that effective assessment is essential to enhance students' learning. For assessment to be effective, it should have the following features: useful, targeted, and sustainable. However, effective assessment is complex and dynamic (Harlen & Gardner, 2010), and its effectiveness relies on teachers' knowledge and understanding of principles of assessment and skills to use these in practice (Edwards, 2013).

There is an added complexity in a subject like Design and Technology (D&T) when implementing effective assessment. This complexity concerns the multidimensional nature of technological activities involving procedural, conceptual, technical, and societal aspects (Boodhoo, 2019; Hope, 2009; Moreland et al., 2007; Stevenson, 2004). Therefore, D&T teachers require the skills to apply assessment in a range of aspects within their classrooms.

Teachers use two assessment types: formative and summative. Formative is utilised to identify learning needs and misconceptions, monitor progress, and improve teaching, while summative to report students' achievement and progress in learning at a particular time (Daugherty, 2010). For Harrison (2013), a simplistic view of the main assessment types might not consider the various assessment purposes, and thus, teachers might have difficulties considering the specific assessment purposes for which they were designed. Also, the way policy documents refer to these terms has created misunderstandings amongst some teachers (Harlen & James, 1997; Klenowski, 2009). The Assessment Reform Group (ARG, 1999) considers formative assessment to lack some features that support learning. Formative assessment is an ongoing assessment that comprises marking and supplying grades/marks to students or adding events or tests to the existing practice (ARG, 1999). Moreover, when enacting formative assessment, students could be passive recipients of teachers' actions and decisions; but when enacting 'assessment for learning', learners are engaged in autonomy and agency (Swaffield, 2011). The term 'assessment for learning' was adopted in this study because the literature identifies a clear list of its characteristics.

Klenowski (2009) defines 'assessment for learning' as 'part of everyday practice by students, teachers and peers that seeks, reflects upon and responds to information from dialogue, demonstration and observation in ways that enhance ongoing learning' (p. 264). This definition highlights that 'assessment for learning' is performed daily, woven with dialogues and interactions amongst the students and their teachers, informing them of the next step they need to take. It presents them with suggestions on how to improve learning. 'Assessment for learning' is child-centred and teacher-led by clarifying the learning intentions and criteria, providing feedback, and using robust questioning for learners so that they can support themselves and one another to become autonomous learners.

12.1.1 Rationale

Throughout my teaching career in Mauritius, I observed that teachers focus more on tests and examinations while neglecting other forms of assessment. It seemed that teachers' main reasons to conduct tests continuously were to assess students' performance to obtain marks that were reported to parents, prepare them for various examinations, and demonstrate their teaching performance. The feedback I received as a teacher-educator while interacting with pre- and in-service teachers also indicated that many teachers continuously assessed through tests.

Since little attempt has been made to explore D&T teachers' 'assessment for learning' practices in Mauritius, I chose to research this area. According to Lam (2016), 'assessment for learning' has been researched extensively in the last two decades. However, its applications for enhancing teaching and learning have been underrepresented in D&T. Hartell et al. (2015) claim that prior research on teachers' assessment practices in Technology Education is rare (the term D&T is associated with Technology Education).

Williams (2016), who analysed numerous Technology Education research studies (1,498 conference publications and journals) from 2006 to 2015, found a lack of research on teachers' assessment practices in Technology Education. Williams (2016) states that over this decade, 'research into areas of Design and Curriculum [original emphasis] have always been fundamental and common areas of inquiry … will continue to dominate research in technology education' (p. 273). D&T teachers 'assessment for learning' practices (such as authentic, practical, project and portfolio assessment) seem under-researched and are therefore worthy of further attention.

These observations, interactions, and gaps in the literature instigated me to question D&T teachers' assessment practices following the completion of their teacher education programmes. Were teachers changing their assessment practices and implementing 'assessment for learning' practices, and if yes, how?

12.1.2 Research Questions

The main research question was: How are the 'assessment for learning' practices of Mauritius D&T teachers framed?

The sub-questions arising from the main question were:

- What are the teachers' 'assessment for learning' practices?
- What guidelines are the teachers using for their 'assessment for learning' practices?
- What rationales do teachers use for implementing 'assessment for learning'?

12.2 How I Tried to Answer the Questions?

An ethnographic methodology was used to explore the D&T teachers' 'assessment for learning' practices in schools. The purpose of ethnography is to understand life through another lens by concentrating on participants' everyday behaviour, gained through fieldwork (Bloor & Wood, 2006). As an ethnographer, I watched what happened, listened to what was said by the D&T teachers, and/or asked questions through informal and formal interviews, and collected documents (Hammersley & Atkinson, 2007).

A mixed methods research design (mixing of qualitative and quantitative methods) was adopted for several reasons. First, it aids to investigate the identified problem from different perspectives, collect diverse types of data, analyse the evidence by using numerous techniques, and interpret findings through various lenses (McKim, 2017). Second, it helps inform the research and answer complex research problems (Denscombe, 2008). Third, it allows the development of the research design stages; one method informed another (Gray, 2014). Finally, it contributes to triangulation of data (Howe, 2012).

Several data collection methods were employed, such as questionnaires, interviews, and observations along with field notes and secondary documents. The questionnaire was the first tool to be administered to D&T teachers. A semi-structured questionnaire was used for several reasons (Johnson & Christensen, 2012). First, information on teachers was required for selection purposes. Second, the teachers' working schedules were required to organise the teacher interviews and for observation purposes. Third, background information on the teachers' initial teacher education and professional learning and development in assessment was needed.

Two types of interviews were used: semi-structured and informal conversational. A semi-structured interview was used because of its flexibility; the sequence of questions can be changed, questions may be added, removed, or modified subject to the evolution of the interview (Rowley, 2012). These interviews allowed probing of respondents' answers to explore the subjective meanings (Gillham, 2005) they attributed to 'assessment for learning'. Eleven group interviews were conducted within teachers' respective schools to encourage them to participate. The informal conventional interview was utilised after teacher observations to better understand 'assessment for learning' decisions. These interviews were scheduled at the end of each lesson.

Both qualitative and quantitative observations were used (Punch & Oancea, 2014). A structured observation approach was adopted to collect qualitative data based on pre-established categories where teachers' 'assessment for learning' behaviour was broken up into small parts. A rubric table was also used as a guideline to identify the 'assessment for learning' categories (see Fig. 12.1). All classes/lessons observed were audio-recorded to collect the quantitative data that were analysed at a later stage.

Three D&T teachers, Renly, Reed, and Bronn (pseudonyms), were selected for observation based on their range of experience: least, middle, and the greatest number

10. Use of evidence to inform instruction: Formative assessment is a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students' achievement of intended instructional outcomes. This dimension focuses on the teacher use of evidence to adjust instruction across the lesson(s) as a whole.

A. Beginning	B. Developing	C. Progressing	D. Extending
There is little or no attempt by the teacher to collect evidence of student learning in the lesson that is connected to the learning goals or criteria for success. OR The collection of evidence is so minimal or inconsistent that there is no way for the teacher to gain insight into student learning. The teacher does not have evidence of student learning to analyse. The teacher has no basis for modifying instructional plans.	There is some evidence that the teacher collects evidence of student learning that is weakly connected to the learning goals or criteria for success. The teacher does not analyse the evidence to identify patterns of understanding/ misunderstanding or make inferences about student strengths and weaknesses. The information is not used to shape instructional decisions. (Observable evidence for this level is characterised by "lost opportunities.")	The teacher uses multiple ways that are connected to the learning goals or criteria for success to collect evidence of student learning throughout the lesson systematically. There is some evidence that the teacher is analysing the evidence to identify patterns of understanding/ misunderstanding or make inferences about student strengths and weaknesses. The information identified patterns, and inferences are not used to shape instructional decisions.	The teacher skillfully uses multiple ways that are connected to the learning goals or criteria for success to collect evidence of student learning throughout the lesson systematically. There are multiple sources of evidence indicating the teacher is analysing the evidence to identify patterns of understanding/ misunderstanding and make inferences about student strengths and weaknesses. The information identified patterns, and inferences are used in powerful ways to shape instructional decisions and advance student learning.

Fig. 12.1 A sample of the rubric table used as a guideline to identify 'assessment for learning' categories

of years of teaching experience. Overall, 25 classroom observations of these three teachers were accomplished. Sequential observations were carried out to have robust evidence of ongoing classroom assessment; each lesson lasted for about 70 min.

Field notes were used to record my 'reactions to the experience … reflections about personal meanings and significance of what [was] observed' (Patton, 2014, p. 388). Thus, note-taking was performed in an attempt to describe the observations. Also, the whiteboard, A3 papers, and textbooks used were photographed.

Non-numeric secondary data were also collected. These personal documents were the teachers' documents, such as weekly, daily lesson, and assessment plans. These personal documents revealed how D&T teachers planned 'assessment for learning'.

12.3 What I Found Out?

The findings presented in this chapter are from an analysis of teachers' practices in the classroom. The five broad themes emerging from the multiple data sources of the classroom practices were as follows: clarifying and sharing learning intentions, learning tasks and classroom discussions, feedback to learners, self- and peer-assessment, and use of assessment information.

12.3.1 Clarifying and Sharing Learning Intentions

The three teachers' classroom observations indicated that they verbally presented an agenda for every lesson at the beginning of each class. They commented on what content would be covered (agenda) without describing what learners should do (learning intentions). For example, one teacher mentioned 'Today's lesson is on angles', instead of clarifying that at the end of the lesson, each learner should be able to construct an angle of 60 degrees. During 24 lessons, the teachers did not mention the learning intentions. At the end of only one lesson, Bronn mentioned a learning intention, but without being specific, for example, 'You should be able to construct these angles'.

Observations revealed that during 23 lessons, the teachers made superficial procedural connections by mentioning what have been covered in previous lessons. Bronn and Renly made links between their previous lessons only at the beginning of two lessons through warm-up questions, which mostly verified if the students could recall facts.

It was evident that none of the teachers referred to their teaching plans during the lessons. An analysis of Reed's plans suggested he did not prepare learning intentions. None of his plans contained learning intentions; lesson plans were not prepared. Informal interviews with Reed revealed that the same plans were used, with adjustments of dates and years, for several years. Reed indicated that he did not 'refer to the National Curriculum Framework: Secondary [(NCFS)] for any planning', but merely used the recommended textbooks and past examination questions from which he identified questions relating to the topic he taught.

Bronn wrote his weekly plans after the lessons, and on several occasions, he would complete the document after two or three lessons. This scenario implied that Bronn used the weekly plan not to prepare teaching, learning, and assessment, but for accountability purposes. An informal conversation with Bronn revealed that he never referred to the NCFS, but merely used textbooks and syllabus.

An analysis of Renly's documents suggested that he planned the learning intentions. However, Renly's daily and weekly plans (for two lessons) indicated that these contained similar learning objectives written in a language appropriate for the teacher only. These learning outcomes were vague and not categorised (conceptual, technical, procedural, and societal). The document analysis revealed that Renly did not plan SMART (specific, measurable, achievable, realistic, and timely) learning targets. An informal interview with Renly revealed that he consulted the NCFS to plan his lessons to ensure 'every [topic] was covered' as per the document. However, Renly admitted that he never referred to the curriculum goals.

12.3.2 Learning Tasks and Classroom Discussions

The observations revealed that the three teachers used appropriate activities aligned with the lessons' content, which provided evidence of students' progress towards set goals. Bronn and Renly selected activities from textbooks and developed activities, aligned with the lessons' agendas for each lesson. However, Reed gave one activity as classwork (from past examination questions or textbooks), and students worked on the same task for two lessons. Even if Reed's activities were adequate, not enough evidence was gathered on students' learning. He explained some drawing techniques and asked students to repeat the drawing procedures.

The observation results indicated that the teachers made inferences on students' progress when activities were set. However, the teachers occasionally missed opportunities (during 14 lessons) to make meaningful inferences on students' progress on the intended learning outcomes, while during 11 lessons, they missed multiple opportunities. The teachers' focus seemed to be on completing their teaching and the set activities without adapting their assessment practices to improve students' learning.

Effective questioning is a key 'assessment for learning' strategies, which teachers use to refine or redirect teaching to address misconceptions or extend a lesson through insights gained on students' progress. The observations indicated that during 12 lessons, the teachers asked about five questions, and during nine lessons, they asked one or two questions at appropriate points to check students' prior knowledge and identify misconceptions. During four lessons, Bronn asked 10 to 15 questions at appropriate points, thus allowing them to understand concepts taught.

Gregory (2016) suggested that the human brain requires a minimum of five to seven seconds to retrieve information stored in the memory and formulate an answer. The findings showed that Bronn and Renly provided about seven to ten seconds wait time to allow students to engage with the oral questions. Conversely, Reed only provided about four seconds of wait time. However, all three teachers often answered their questions before any student could respond.

The observations also suggested that although the teachers monitored students' work regularly, they did not use questioning strategies effectively to collect evidence of students' misconceptions. Reed rarely questioned students who had difficulties. The questioning strategies used by Renly provided evidence for some students only; while Bronn was inconsistent in using questioning strategies, which were not systematically structured for students to benefit. The teachers primarily focussed on indicating the steps to complete the activities.

12.3.3 Feedback to Learners

The teachers mostly provided verbal feedback on students' ongoing work. They regularly identified the students' mistakes and told them what they needed to do next and how they needed to solve a problem or how to apply concepts. However, these verbal feedbacks were short and often ended abruptly. For example, one teacher said, ‘the outlines should be darker’. The feedback during questioning did not allow a full exploration of the ideas or issues discussed. When providing verbal feedback, the teachers occasionally built on students’ responses to encourage them in their learning.

Since the observed lessons were based on the D&T component of ‘graphic products’, the written feedback was not only in the form of comments but sketches and drawings (done with drafting tools). Bronn and Renly provided some individualised written comments, but Reed gave none. However, the written feedback was provided only on completed activities. Bronn provided fewer written comments by writing some technical terms, often one or two words. The teachers frequently used drawings and sketches to explain or discuss concepts that students struggled to understand. However, the teachers mostly gave brief and quick demonstrations.

The teachers’ written (including marks) and verbal feedback on completed tasks were not timely. Renly and Bronn provided feedback on completed tasks within two weeks. The students who struggled with the tasks took more time to have their work checked by their teacher. Reed took almost three weeks to correct the tasks and provide verbal feedback and a score. In some instances, several students did not receive feedback.

12.3.4 Self- and Peer-Assessment

The findings under this theme helped understand whether D&T teachers considered learner autonomy (self- and peer-assessment) when implementing ‘assessment for learning’. Autonomy is based on the belief that ‘assessment for learning’ is more effective when learners are actively involved. The observations revealed that D&T teachers deprived the students’ of opportunities to engage in self-assessment. When questioned about using self-assessment, the teachers claimed that they do not think students are interested in or have the required skills to self-assess their work. Bronn argued that only one or two students could self-assess their tasks, so it was not worth spending time on self-assessment.

Peer-assessment contributes to enhancing students’ learning through two mechanisms. First, students spend increased time on tasks, and second, they pay more attention to feedback within a social dimension, which consequently intensifies their efforts (Gielen et al., 2011). However, the findings showed that the teachers deprived students of peer-assessment opportunities. Informal interviews with the teachers suggested that peer-assessment would disrupt their teaching, as it is time-consuming, and students do not possess peer-assessment skills. The teachers added that students would focus less on the task and spend more time talking about unrelated issues.

12.3.5 Use of Assessment Information

When implementing 'assessment for learning' practices, Davies (2011) recommended that teachers collect and record assessment information to examine students' learning that is fundamental in planning, adjusting, and transforming their practice, including 'assessment for learning' practices. The findings highlighted that the teachers collected evidence of students' learning but recorded superficial information concerning students' difficulties. Thus, the teachers were not able to indicate students' common strengths and weaknesses or a particular student's specific challenges. An analysis of Bronn's documents indicated that the 'assessment for learning' evidence recorded could hardly be used to improve learning and teaching.

When Renly carried out 'assessment for learning', he monitored students' activities and recorded some evidence on a sheet. Renly aimed to ensure that students completed the set tasks successfully. Whenever he asked a student to rework a particular task, he recorded this information. However, it is evident that on several occasions, he did not verify students' activities (indicated by blank spaces on the monitoring sheet). Renly's monitoring sheet indicated only those students who had completed their work. The 'to rework' remark only allowed Renly to know who had difficulties completing the task, but not the specific challenges students faced, which could be used to adjust/transform his practice.

The findings indicated that the teachers were not reflecting effectively when monitoring assessment activities. The informal interview findings suggested that the teachers did not try to identify the causes of students' difficulties, such as having difficulties in manipulating drafting tools or understanding drawing concepts. Reflection on assessment information allows questioning and analysing one's practice and assumptions (Burbank et al., 2016). However, the evidence indicates that the teachers did not perform any reflection after completing their teaching and 'assessment for learning' practices. Bronn and Renly occasionally put a remark indicating whether they completed a particular lesson or which part of the lesson was unsuccessful. Informal interviews confirmed that they did not practice any reflection with the intent to transform their assessment and/or teaching practices.

The informal interviews with the teachers on transforming their 'assessment for learning' practices highlighted different opinions. Bronn and Reed were convinced they had enough experience to conduct 'assessment for learning' efficiently and that their practices did not demand any change. Conversely, Renly claimed that he was willing to reflect on and transform his 'assessment for learning' practices, but was unable due to time constraints, and pressure to complete the syllabus and prepare students for examinations.

12.4 How This Might Be Used to Improve Teaching, Assessment, and Learning?

Stables (2015) indicates that classroom assessment practices still follow behaviourist perspectives, which conflict with constructivist perspectives. Under behaviourist perspectives, assessment is viewed as the process of verifying whether learners received the transferred information and could recall what they learned (Leonard, 2002). However, under constructivist perspectives, learners are at the centre of the learning environment and actively participate in constructing knowledge. Assessment under constructivist perspectives follows a continuous and ongoing process, and methods such as authentic assessment and performance assessment are used (Porcaro, 2011).

Hence, Stables (2015) recommends that assessment approaches that support learning should be adopted in D&T. The findings indicate that the D&T teachers 'assessment for learning' practices rarely served the fundamental purpose of 'assessment for learning'. Thus, some strategies necessary to effect teaching, assessment, and learning in D&T are planning learning intentions and tasks, asking good questions, promoting classroom dialogue and providing useful feedback, and improving practice via communities of practice.

12.4.1 Planning of Learning Intentions and Tasks

The key to good teaching, assessment, and achievement of sustainable progress lies in effective preparation and planning. For Butt (2008), most teachers who have taught successfully for several years, have built a bank of lesson plans with clear learning intentions and tasks to quickly select for different classes. To a great degree, the National Curricula, syllabus, and textbooks give limited support to teachers to plan lessons, and principally learning intentions. These guidelines consist of list of concepts, contents, and activities with little direction on planning steps to realise successful teaching and assessment (Westbury, 2008). Hence, it is the responsibility of teachers to develop appropriate learning intentions, which need to be clarified and shared with learners at the beginning of each lesson and when required during lessons (Moss & Brookhart, 2009).

One way for D&T teachers to identify what they need to teach is to articulate explicit learning intentions that students can understand and achieve (Spendlove, 2015). The SMART goal-setting process helps teachers ensure that the learning intentions are within reasonable limits (Lydotta & Fratto, 2012). When D&T learning intentions are grouped into conceptual, societal, technical, and procedural categories and translated into students' language, then, it is easier for teachers to determine how their students might progress towards targeted learning intentions to enable relevant learning (Fox-Turnbull, 2015). These learning intentions are also used for asking questions, providing feedback and gathering assessment data on students' learning, and identifying, planning, and/or developing appropriate tasks (Biggs, 1996).

When planning activities, if teachers are unclear about technological ideas and processes, Moreland et al. (2008) warn that their interactions with students may not focus on technology. Instead, teachers would emphasise praising students concerning task completion and other skills (Jones & Moreland, 2004). To interact more efficiently and confidently, Moreland et al. (2008) propose that teachers could become more aware of the demands of assessment activities through rehearsals, which would also indicate potential problems. Also, it would ascertain the technological knowledge and skills required by teachers for the activities. For example, a teacher might predict if the allocated amount of material for a specific project (assessment activity) would be appropriate or not. On top of planning tasks, asking good questions is crucial for students' learning.

12.4.2 Asking Good Questions

One key teachers' role when enacting 'assessment for learning' is to promote a thinking classroom. This philosophy can be achieved by asking good questions and by encouraging students to express themselves and reflect on their ideas, leading them through such interactions to develop and change their thinking (Black & Atkinson, 2007). However, many teachers frequently make mistakes when enacting 'assessment for learning' because they are ill-equipped with questioning techniques. Questioning mistakes include asking lower-level questions, not giving students enough time to answer, not encouraging them to answer or ask questions, and not probing beyond a single answer (Gregory, 2016). On the student side, habitually only a few students dominate classroom interactions.

Questioning does not come naturally to many teachers because they are not used to thinking in terms of questions but answers (Sardareh et al., 2014). Teachers may think about questions in the following way: questions that direct, describe, and compare and interpret experience, and those allowing learners to think creatively, generalise, and transfer learning to new contexts and solving problems (Minton, 2005). In this way, teachers will ask factual and focus more on deep-learning level type of questions (Jimaa, 2011).

At the outset, Bloom's cognitive domain taxonomies (Bloom et al., 1956) are useful for developing questions. Some thought-provoking questions are indicated:

- Reasoning question: Why do you think it will work?
- Reflection and collaboration questions: What can be added to Linda's response? How can Mike's idea or drawing be improved?
- Self-reflection question: Why did not you opt for a different approach to solve the problem?
- Analysis questions: How many possibilities can you think of? What are the similarities and differences between the two objects?

As indicated earlier, questioning techniques facilitate meaningful students' conversations. Moreover, through questioning, teachers gain many opportunities to provide useful feedback to learners.

12.4.3 Promoting Classroom Dialogue and Providing Useful Feedback

Classroom dialogue is fundamental when D&T teachers enact 'assessment for learning'. Moreland et al. (2008) suggest that students should be provided with opportunities to express themselves, discuss and debate their ideas with peers and the teacher. For example, when exploring technological ideas, it is through the designing and talking that students start realising what they know, what they can do, how well they know, and how well they can do a particular activity (Moreland et al., 2008). For effective learning to occur, classroom talk should be rich enough for learners to reveal their concerns and ideas (Moreland et al., 2008).

Listening and interacting with students enables teachers to provide useful feedback and suggest ways of improvement. However, Brookhart (2011) warns that feedback is not only about highlighting incorrect answers and providing correct solutions to students. Feedback means providing students with information about their learning. Moreland et al. (2008) suggest that detailed feedback through comments, associated with students' actual achievements or competencies, is vital for improving their learning. In D&T, teachers need to provide learners with information (descriptive feedback) that aids them in realising how well they have done, how well they are doing, where they might go next and how they might get there.

Apart from identifying strengths, weaknesses, and the next learning steps, feedback should also focus on negotiating learning intentions and expectations. During the lesson's implementation and when conducting assessment, as learners became self-reflective about their learning progress and based on their needs, the learning intentions could require modifications (Compton & Harwood, 2003; Moreland et al., 2008). Therefore, a re-alignment of the learning intentions could be required to enable students to progress. Feedback is also essential for teachers to improve their teaching, and one way to transform practice is through Communities of practices.

12.4.4 Improving Practice via Communities of Practice

In using the term community, Lave and Wenger (1991) suggest that they 'do not imply some primordial culture-sharing entity' (p. 98). The authors mean that members of the community have diverse interests, contribute to activity, and hold various notions. In the community of practice, groups of people jointly work on regularly valued learning activities (Fetterman, 2002; Wenger, 1999). This social process results in forming social relationships amongst the individuals involved (Farnsworth et al., 2016), which could help D&T teachers understand and enact the key features of 'assessment and learning'.

A community of practice is classified along three key dimensions—joint enterprise, mutual engagement, and shared repertoire (Wenger, 1998). The joint enterprise is about negotiating the goals, procedures, and processes unifying the members on a mutual and continuous basis. Mutual engagement involves engaging members to interact and build a relationship binding them into a social entity. The shared repertoire is the community of practice's apparent outcome, which is about sharing collective resources (stories, reflections, concepts, plans, activities, and tools) that partners acquired over time.

Reflecting on three dimensions, D&T teachers' community of practice could be described as a 'group of [D&T teachers] sharing common concerns, set of problems, or a passion about a topic [such as feedback, use of assessment data, and self- and peer-assessment] and who deepen their knowledge and expertise in this area by interacting on an ongoing basis' (Culver & Trudel, 2006, p. 98). Hence an understanding of communities of practice could be helpful to D&T teachers, as members of the community, to jointly construct explanations of, for example, what they do when enacting 'assessment for learning', how they do it, why they do it, and how they could enhance it.

Whether communities of practice arise naturally or not, the institution always influences their development. Most communities of practice exist irrespective of an institution's recognition; a few could require initiation and support, while others could flourish on their own (Wenger, 1998). Wenger claims that many communities are best left alone as they might fade away under an institution's attention. Wenger adds that the majority flourish under some attention, as long as this attention does not restrict their self-organising drive.

Irrespective of the creation and existence of communities of practice, teachers' development relies on internal leadership (Wenger, 1998). Internal leadership could take many forms, such as boundary, institutional, and day-to-day leadership. These leadership positions could be formal or informal, but to be effective, managers and others (D&T teachers and inspectors) have to 'work with the communities of practice from the inside rather than merely attempt to design them or manipulate them from outside' (Wenger, 1998, p. 7).

Leadership within communities of practice is seen as distributed. Therefore, when D&T teachers are involved in communities of practice, they have a shared understanding of their field, which guides them to extend and improve their practices based on that understanding. Roberts and Pruitt (2009) claim that teachers are accepted as 'experts and sometimes are more effective than outside consultants' (p. 57). However, teachers would not be experts in all the domains of their 'assessment for learning' practices, which is also context-dependent. Thus, in several contexts, recognised experts' contributions could be brought in through professional learning and development to enhance teachers' 'assessment for learning' practices (Harlen, 2010; Wenger, 1998).

12.5 Conclusion

The fundamental purpose of 'assessment for learning' is to enhance students' learning and help them become autonomous learners. However, the research findings revealed that D&T teachers' 'assessment for learning' practices rarely served the fundamental purpose of 'assessment for learning'. Based on the findings, some insights for enhancing D&T teachers' teaching and assessment practices were provided through the following: developing learning intentions and tasks, posing good questions, using classroom dialogue, and giving useful feedback, and transforming practice via communities of practice.

12.5.1 How This Research Could Be Developed Further?

Although this study involved a small sample, it raises questions about whether D&T teachers in other schools have similar 'assessment for learning' beliefs and practices. Hence, additional research may be required to investigate D&T teachers' 'assessment for learning' practices at various schools, levels, and other components of D&T, such as 'product design' and 'practical technology'.

Despite the various guidelines that the teachers used, the study found that teachers had a narrow understanding of 'assessment for learning' and seemed confused about the various assessment purposes. Accordingly, investigations of teacher-educators', inspectors', quality assurance officers', and principals' 'assessment for learning' literacy would be useful.

This study indicated that D&T teachers' 'assessment for learning' knowledge is limited, indicating that teacher education in D&T lacks the appropriate structure and knowledge to guide and support teachers' 'assessment for learning' practices. Thus, a comparative study of 'assessment for learning' content of the D&T teacher education programme of Mauritius with other comparable countries would be helpful as it could indicate areas of improvement in structure and content.

12.5.2 Research Suggestions for Teachers

Research shows that teachers need to be supported by professional learning and development and involved in communities of practice in several areas, such as beliefs, contextual factors, and 'assessment for learning' literacy (Barnes et al., 2015; Koh, 2011; Poskitt, 2014). Based on this study's findings, it is suggested that teachers should reflect on their practice and be involved in research. Hence, research might be conducted to investigate how teachers' 'assessment for learning' practices evolve when sustained with professional learning and development, communities of practice, and when involved in reflection and research. Teachers could also research their own 'assessment for learning' practices, which could be shared with other teachers and key stakeholders.

References

Assessment Reform Group. (1999). *Assessment for learning: Beyond the black box*. Nuffield Foundation website: http://www.nuffieldfoundation.org/assessment-reform-group.

Barnes, N., Fives, H., & Dacey, C. M. (2015). Teachers' beliefs about assessment. In H. Fives & M. G. Gill (Eds.), *International handbook of research on teachers' beliefs* (pp. 284–300). Routledge.

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education, 32*(3), 347–364. https://doi.org/10.1007/BF00138871

Black, P., & Atkinson, S. (2007). Useful assessment for design & technology: Formative assessment, learning and teaching. In D. Barlex (Ed.), *Design and technology: For the next generation* (pp. 199–215). Cliffeco & Company.

Bloom, B., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational Objectives: The classification of educational goals*. Handbook 1: Cognitive domain. David McKay Company.

Bloor, M., & Wood, F. (2006). *Keywords in qualitative methods: A vocabulary of research concepts*. Sage.

Boodhoo, C. (2019). Teaching technology teacher education—Assessment best practice. In M. A. Peters (Ed.), *Encyclopedia of teacher education*. Springer. https://doi.org/10.1007/978-981-13-1179-6_163-1.

Brookhart, S. M. (2011). Tailoring feedback: Effective feedback should be adjusted depending on the needs of the learner. *Education Digest: Essential Readings Condensed for Quick Review, 76*(9), 33–36.

Burbank, M. D., Ramirez, L. A., & Bates, A. J. (2016). The impact of critically reflective teaching: A continuum of rhetoric. *Action in Teacher Education, 38*(2), 104–119. https://doi.org/10.1080/01626620.2016.1155095

Butt, G. (2008). *Lesson planning* (3rd ed.). Continuum.

Compton, V., & Harwood, C. (2003). Enhancing technological practice: An assessment framework for technology education in New Zealand. *International Journal of Technology and Design Education, 13*(1), 1–26. https://doi.org/10.1023/B:ITDE.0000039567.67842.c3

Cowie, B., Moreland, J., Otrel-Cass, K., & Jones, A. (2008). More than talk and writing: Exploring the multimodal nature of classroom interactions. *University of Waikato Research Commons*. http://researchcommons.waikato.ac.nz/handle/10289/7029.

Culver, D., & Trudel, P. (2006). Cultivating coaches' communities of practice: Developing the potential for learning through interactions. In R. Jones (Ed.), *The sports coach as educator: Reconceptualising sports coaching* (pp. 97–112). Routledge.

Daugherty, R. (2010). Summative assessment by teachers. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International encyclopedia of education* (3rd ed., pp. 384–391). https://doi.org/10.1016/B978-0-08-044894-7.00363-8; http://www.sciencedirect.com/science/article/pii/B9780080448947003638.

Davies, A. (2011). *Making classroom assessment work* (3rd ed.). Solution Tree Press.

Denscombe, M. (2008). Communities of practice: A research paradigm for the mixed methods approach. *Journal of Mixed Methods Research, 2*(3), 270–283. https://doi.org/10.1177/1558689808316807

Edwards, F. (2013). Assessing New Zealand high school science: Considerations for teachers' assessment literacy. *Asia-Pacific Forum on Science Learning & Teaching, 14*(2), 1–17.

Farnsworth, V., Kleanthous, I., & Wenger-Trayner, E. (2016). Communities of practice as a social theory of learning: A conversation with Etienne Wenger. *British Journal of Educational Studies, 64*(2), 139–160. https://doi.org/10.1080/00071005.2015.1133799

Fetterman, D. M. (2002). Empowerment evaluation: Building communities of practice and a culture of learning. *American Journal of Community Psychology, 30*(1), 89–102. https://doi.org/10.1023/A:1014324218388

Fox-Turnbull, W. (2015). Conversations to support learning in technology education. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education* (pp. 99–120). Springer.

Gielen, S., Dochy, F., Onghena, P., Struyven, K., & Smeets, S. (2011). Goals of peer assessment and their associated quality concepts. *Studies in Higher Education, 36*(6), 719–735. https://doi.org/10.1080/03075071003759037

Gillham, B. (2005). *Research interviewing: The range of techniques*. Open University Press.

Gray, D. (2014). *Doing research in the real world* (3rd ed.). Sage.

Gregory, G. H. (2016). *Teacher as activator of learning*. Corwin Press.

Hammersley, M., & Atkinson, P. (2007). *Ethnography: Principles in practice* (3rd ed.). Routledge.

Harlen, W. (2010). Professional learning to support teacher assessment. In J. Gardner, W. Harlen, L. Hayward, & G. Stobart (Eds.), *Developing teacher assessment* (pp. 100–129). Open University Press.

Harlen, W., & Gardner, J. (2010). Assessment to support learning. In J. Gardner, W. Harlen, L. Hayward, G. Stobart, & M. Montgomery (Eds.), *Developing teacher assessment* (pp. 15–28). Open University Press.

Harlen, W., & James, M. (1997). Assessment and learning: Differences and relationships between formative and summative assessment. *Assessment in Education: Principles, Policy & Practice, 4*(3), 365–379. https://doi.org/10.1080/0969594970040304

Harrison, C. (2013). Testing times: Reforming classroom teaching through assessment. In J. Clifton (Ed.), *Excellence and equity: Tackling educational disadvantage in England's secondary schools* (pp. 71–77). Institute of Public Policy Research.

Hartell, E., Gumaelius, L., & Svärdh, J. (2015). Investigating technology teachers' self-efficacy on assessment. *International Journal of Technology and Design Education, 25*(3), 321–337. https://doi.org/10.1007/s10798-014-9285-9

Hope, G. (2009). Beyond knowing how to make it work: The conceptual foundations of designing. *Design and Technology Education, 14*(1), 49–55.

Howe, K. R. (2012). Mixed methods, triangulation, and causal explanation. *Journal of Mixed Methods Research, 6*(2), 89–96. https://doi.org/10.1177/1558689812437187

Jimaa, S. (2011). The impact of assessment on students learning. *Procedia—Social and Behavioral Sciences, 28*, 718–721. https://doi.org/10.1016/j.sbspro.2011.11.133

Johnson, B., & Christensen, L. B. (2012). *Educational research: Quantitative, qualitative, and mixed approaches* (4th ed.). Sage Publications.

Jones, A., & Moreland, J. (2004). Enhancing practicing primary school teachers' pedagogical content knowledge in technology. *International Journal of Technology and Design Education, 14*(2), 121–140. https://doi.org/10.1023/B:ITDE.0000026513.48316.39

Klenowski, V. (2009). Assessment for learning revisited: An Asia-Pacific perspective. *Assessment in Education: Principles, Policy & Practice, 16*(3), 263–268. https://doi.org/10.1080/09695940903319646

Koh, K. H. (2011). Improving teachers' assessment literacy through professional development. *Teaching Education, 22*(3), 255–276. https://doi.org/10.1080/10476210.2011.593164

Lam, R. (2016). Assessment as learning: Examining a cycle of teaching, learning, and assessment of writing in the portfolio-based classroom. *Studies in Higher Education, 41*(11), 1900–1917. https://doi.org/10.1080/03075079.2014.999317

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Leonard, D. C. (2002). *Learning theories: A to Z*. Greenwood Press.

Lydotta, T. M., & Fratto, J. M. (2012). *Transforming learning through 21st century skills*. Pearson.
McKim, C. A. (2017). The value of mixed methods research: A mixed methods study. *Journal of Mixed Methods Research, 11*(2), 202–222. https://doi.org/10.1177/1558689815607096
Minton, D. (2005). *Teaching skills in further & adult education* (3rd ed.). Thomson Learning.
Moreland, J., Cowie, B., & Jones, A. (2007). Assessment for learning in primary technology classrooms. *Design and Technology Education: An International Journal*, *12*(2), 37–48. http://researchcommons.waikato.ac.nz/handle/10289/2096.
Moreland, J., Jones, A., & Barlex, D. (2008). *Design and technology inside the black box: Assessment for learning in the design and technology classroom*. GL Assessment.
Moss, C. M., & Brookhart, S. M. (2009). *Advancing formative assessment in every classroom: A guide for instructional leaders*. ASCD.
Patton, M. (2014). *Qualitative research and evaluation methods* (4th ed.). Sage.
Porcaro, D. (2011). Applying constructivism in instructivist learning cultures. *Multicultural Education & Technology Journal, 5*(1), 39–54. https://doi.org/10.1108/17504971111121919
Poskitt, J. (2014). Transforming professional learning and practice in assessment for learning. *The Curriculum Journal, 25*(4), 542–566. https://doi.org/10.1080/09585176.2014.981557
Punch, K. F., & Oancea, A. (2014). *Introduction to research methods in education* (2nd ed.). Sage Publications Ltd.
Roberts, S. M., & Pruitt, E. Z. (2009). *Schools as professional learning communities: Collaborative activities and strategies for professional development* (2nd ed.). Corwin Press.
Rowley, J. (2012). Conducting research interviews. *Management Research Review, 35*(3/4), 260–271. https://doi.org/10.1108/01409171211210154
Sardareh, S., Saad, M., Othman, A., & Me, R. (2014). ESL teachers' questioning technique in an assessment for learning context: Promising or problematic? *International Education Studies, 7*(9), 161–174. https://doi.org/10.5539/ies.v7n9p161
Spendlove, D. (2015). *100 ideas for secondary teachers: Assessment for learning*. Bloomsbury Publishing.
Stables, K. (2015). Assessment: Feedback from our pasts, feedforward for our futures. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education* (pp. 121–142). Springer.
Stevenson, J. (2004). Developing technological knowledge. *International Journal of Technology and Design Education, 14*(1), 5–19. https://doi.org/10.1023/B:ITDE.0000007361.62177.07
Swaffield, S. (2011). Getting to the heart of authentic assessment for learning. *Assessment in Education: Principles, Policy & Practice, 18*(4), 433–449. https://doi.org/10.1080/0969594X.2011.582838
Warwick, P., Shaw, S., & Johnson, M. (2015). Assessment for learning in international contexts: Exploring shared and divergent dimensions in teacher values and practices. *The Curriculum Journal, 26*(1), 39–69. https://doi.org/10.1080/09585176.2014.975732
Wenger, E. (1998). Communities of practice: Learning as a social system. *Systems Thinker, 9*(5), 1–5.
Wenger, E. (1999). *Communities of practice: Learning, meaning and identity*. Cambridge University Press.
Westbury, I. (2008). Making curricula: Why do states make curricula and how? In F. M. Connelly, M. F. He, & J. Phillion (Eds.), *The sage handbook of curriculum and instruction* (pp. 45–65). Sage.
Williams, P. J. (2016). Learning through research. In H. Middleton (Ed.), *Proceedings of the 9th Biennial International Conference on Technology Education* (pp. 269–275). Griffith University.

Dr. Chandan Boodhoo is a Lecturer in the Department of Curriculum Studies and Evaluation at the Mauritius Institute of Education (MIE) since 2012. He taught Design and Technology in both private and state secondary schools in the Republic of Mauritius. He holds a Degree in

Manufacturing Engineering and Postgraduate Certificate in Education in D&T from the University of Mauritius and the MIE, respectively. As a recipient of two Commonwealth Scholarships, he pursued his Postgraduate diploma, Master's, and Doctoral degree in Education at the University of Waikato, New Zealand.

Chapter 13
Integrating Design and Technology with Entrepreneurship in Lesotho

Nthoesele Mohlomi

Abstract The global economies and regional imperatives influence Design and Technology to pave learners' way to further their education but at the same time nurture skills which allow learners to be absorbed by the world of work with ease. This dual objective has coerced Lesotho to reform and commence Design and Technology (D&T) at the primary level with an emphasis on local materials usage and integration of entrepreneurship concepts. The reform is informed by the Curriculum and Assessment Policy 2009. This reform has influenced how the teacher blends planned actions towards learning with self-directed behaviour and self-determination of the students learning needs (academagogical). This chapter reports on the integration and nature of Design and Technology in the primary and secondary education of Lesotho, particularly academagogy as defined by Jones et al. (The promise of andragogy, heutagogy and academagogy to enterprise and entrepreneurship education pedagogy. University of Wales Trinity Saint David, Carmarthen, UK.2019). The data for the chapter was collected through interviews, observations, and written documents. The findings show that the concept of entrepreneurship integrated with Design and Technology has relevance to local economies and takes cognizance of emerging socio-economic activities in Lesotho. Conversely, there is a challenge to educators' planned actions towards learning as teacher's backgrounds and norms are still inclined towards a colonial inherited educational system.

Keywords Academagogy · Integration · Creativity and entrepreneurship · Design and technology

13.1 Introduction

The rationale for the chapter is to elaborate on how the teaching of Design and Technology (D&T) is subjected to the interconnection and influence of the education system, regional imperatives, and global economies. In this context the chapter

N. Mohlomi (✉)
National Curriculum Development Centre (NCDC), Maseru, Lesotho

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_13

intends to answer three main questions, namely: What is the nature and purpose of Design and Technology (D&T); why integrate D&T with Entrepreneurship; and what are the roles of teachers in implementing the integrated D&T?

In answering these questions, the chapter will view D&T within the broader educational system where the light will be shed on the nature and purpose of D&T. Thereafter, D&T will be discussed as a subject in secondary schools of Lesotho. Followed by the Curriculum and Assessment Policy (CAP) 2009 expectations on the practice/roles of teachers and what happened when teachers integrated D&T with Entrepreneurship. This chapter concludes by proposing a set of strategies to improve teaching and learning of D&T integrated with Entrepreneurship, drawn from the findings of this research.

13.2 Design and Technology in the Broader Educational System

Design and Technology (D&T) globally is part of secondary education while other countries start it at the primary level. At the secondary level, the purpose of D&T is to prepare graduates to further their education but also to allow them to enter the world of work/occupation with ease. The dual-purpose/expectations are demanding not only to teachers' in the practice but also to the policymakers. Therefore, a teacher must understand the purpose of the educational system with D&T even before going to practice/teach in the classroom.

In the classroom, it is also vital for a teacher to understand the nature of the subject to be able to practice planned actions towards learning in the D&T. Nature is the perspective at which the country views or perceive the subject. Different countries view the nature of D&T differently due to diverse backgrounds, socio-economic status, as well as political spheres (ed. Jackson, 2002). Some common views/approaches towards D&T are:

- Craft-oriented view
- Industry-oriented view
- Science-oriented view
- "High-tech" view
- Engineering concepts view
- Key competencies view
- Design-oriented view
- Social issues view (ed. Jackson, 2002:289).

It is not only the viewpoint/approach of the country towards D&T that influences the practice in class but also the balancing of the dual-purpose of the subject. The nature of D&T is different in each country but the dual-purpose for teaching D&T is common in African countries. Firstly, to allow learners to further their education from basic level to tertiary in courses that country's D&T viewpoint is inclined to.

Secondly, to link the learners' school context with the world of work (Biemans et al, 2004; DfE, 2013; Van Aar, van Oenen, & van Keulen, 2016). Consequently, the dual-purpose must be fulfilled by D&T as a subject from the policy level via a teacher to a learner.

13.3 Background of Design and Technology (D&T) with Entrepreneurship in Lesotho Together with the Role of the Teachers

Lesotho with her strategy of integrating D&T with Entrepreneurship aims to achieve the dual-purpose of the subject at both primary and secondary levels. Lesotho introduced a diversification policy (practical subjects) during 1975 in secondary schools to equip learners with skills for self-reliance (Evaluation of Secondary Schools Curriculum Report, 1993). Among practical subjects introduced there were the crafts of woodwork, metalwork, and technical drawing (Gretsinger, 1984).

D&T is the successor of the crafts in Lesotho and was offered from 2010. It was the best option after the Cambridge International Examination (CIE) as the accreditor of Lesotho no longer accredited woodwork, metalwork, and technical drawing. In 2012 Lesotho implemented the Curriculum and Assessment Policy (CAP) 2009 concepts in classrooms.

Design and Technology (D&T) with Entrepreneurship is one of the CAP 2009 concepts. D&T is hosted in the Creativity and Entrepreneurship (C&E) learning area. The CAP 2009 reform was phased in annually from Grade three and in 2020 was at Grade 12 at the secondary level.

The Curriculum and Assessment Policy (CAP) 2009 has expectations on teachers' practice in planning effective learning. One of the CAP's 2009 expectations and rationale for integration is that production and work-related competencies together with talents are nurtured at an early age as opposed to the 1975 diversification policy which emphasized self-reliance at an older age.

Subsequently, D&T integrated with Entrepreneurship starts from Grade one as opposed to previously when D&T was starting at Grade eight. The role of teachers in D&T integrated with Entrepreneurship is to inculcate the skills, knowledge, attitudes, and values of these disciplines at an early stage of life. These are expected to allow learners to realize their creative capacity with the resources in their environment (local and global), and as a result, be capacitated to be socially and economically productive in their everyday living.

On one hand, the D&T syllabus as a successor of a craft subject focusses on:

(a) promoting problem-solving activities with design activities
(b) developing appropriate technical skills to enable: the realization of solutions to design, usage of a range of materials, and the appropriate manipulative skills
(c) developing an understanding of some aspects of technological activities

(d) developing appropriate graphical skills to enable full engagement in design activity
(e) developing awareness of safety and precautions in a working environment
(f) developing an awareness of Lesotho heritage and culture (Design and Technology Syllabus 0189, 2015:4).

Stables and Buck (2019) concur and stipulate that the whole focus of Design and Technology aims at artefact production, evaluation, and the relationship with its environment.

On the other hand, Entrepreneurship as is defined by the National Curriculum Development Centre (NCDC) of Lesotho focus is:

(a) To nurture and identify the passion and talents of learners.
(b) not specifically in business but business can be part of entrepreneurship.
(c) enabling learners to be visionary,
(d) risk-takers,
(e) team players,
(f) problem solvers,
(g) creative (produce innovative ideas) and
(h) innovative (implement) on what they are passionate about.

What learners are passionate about should be socially and economically productive for them and the people around them while they have a positive mindset of success on what they are doing. The role of the teacher and how they should integrate the two are captured in the syllabus of Creativity and Entrepreneurship (C&E) as the learning area. Considering the Lesotho background it is logical to view how the three main questions were answered.

13.4 How the Questions Are Answered

The research used a qualitative approach that follows an interpretivist philosophy. The data was collected through interviews, observations, and written documents and the analysis seeks to gain a deeper understanding of the three main research questions. The participants were purposefully selected from 70 schools that were piloting Creativity and Entrepreneurship (C&E). The researcher as part of the National Curriculum Development Centre (NCDC) training team conducted interviews during teacher training sessions. Two teachers from urban and two from rural areas were scheduled for interviews.

Two observations were made per grade on 50 of the piloting schools. The first observation was made three months after training as a follow-up, and focussed on how teachers apply their training. The second observation was made four months after the first one. The observations were done in four grades, namely five to eight involving 10- to 13-year olds. The observations were done by the entire NCDC subjects' specialists with the purpose to monitor and evaluate the piloting schools.

The subjects' specialists were given the same evaluation tool and Creativity and Entrepreneurship was part of the learning areas/subjects being observed from Grades five to eight.

The themes were revealed during the interviews and observations focussing on the frequency of occurrence of an issue. The content of the interview as well as the context of the interviewee were analysed to get the deeper understanding of the issue investigated. The same procedure of content and context analysis was used on the observations. Moreover, on the interviews and observations were a narrative analysis that focussed on the intention, understanding, and meanings displayed by the participants. The documents were analysed and evaluated on the relevance of their content in relation to the issue investigated and in the context of Lesotho. The findings were the results of both the interviews, observations, and document analysis.

13.5 What I Found Out

The findings are developed in the context of the learning area of Creativity and Entrepreneurship (C&E) as Design and Technology (D&T) is integrated with Entrepreneurship in this learning area. The learning area is composed of Business Education, ICT (Information Communication Technology), Home Economics, Art, Crafts, Music and Dance, Technical Subjects, as well as Theatre and Drama. The Curriculum and Assessment Policy (CAP) 2009 has introduced five learning areas to replace traditional subjects.

The rationale for introducing learning areas is captured in the CAP 2009 document; however, for this learning area, one of the reasons is to enhance learners' ability and capability of production and work-related competencies. Generally, CAP 2009 in the learning area of C&E focussed on nurturing practical skills and talents with business fusion. The aim is for the learners to act out their knowledge in their communities.

Teachers are positive about CAP's 2009 vision, but they fall short on facilitating it due to their educational background. The integration is a challenge to teachers because they were trained in unintegrated, compartmentalized traditional subjects during their teacher training and schooling. The National Curriculum Development Centre (NCDC) has provided some training on the aim and purpose of CAP 2009 as well as integration. However, teachers mentioned that elements of the training were not adequate.

Findings have revealed two groups of teachers: some who can exploit suitable resources around their schools, use them profitably regardless of their school location and link school with the world of work, while others are only using the prescribed materials without linking them either to the environment around or industry. The personality and background of each teacher are the major factors that lead to their performance, as all teachers are trained in the same manner by NCDC. The C&E learning area findings will be categorized under three headings: the *Curriculum and*

Assessment Policy 2009 (CAP 2009), the teacher's role, and the expectations on learners.

13.6 Curriculum and Assessment Policy 2009 (CAP 2009)

CAP 2009 presents a vision that life is integrated, and that life challenges are better addressed through simultaneous application of concepts from different disciplines. Therefore, CAP 2009 aim is not solely for learners to pass examinations but also to nurture the learners to be socially and economically productive in the society. As a result, proposes production and work-related competencies and talents to be nurtured from an early age. Therefore, the C&E syllabus made a provision that the content is practically orientated with features that can be directly observed in real-life situations without much abstraction. The integrated C&E syllabus illuminates the real-life situations within the content, unlike the previous compartmentalized syllabi where that was not the case. The C&E learning area is organized in such a way that it utilizes projects, themes, and scenarios which are familiar to the immediate environment of learners.

The rationale behind these projects is to allow teaching and learning to explore the real-life context to the maximum: expose the linkages and collaboration of the disciplines within the C&E learning area and allow learners to vividly realize how the subject content can enhance their everyday life situations (help them survive socially and economically). In each project, teachers specifically at the secondary level are expected to see how their specialization content is integrated and can be applied to realize the project outcomes.

D&T is about production, relationship with the environment, and evaluation of an artefact, while Entrepreneurship in C&E is the state of mind where a person has a passion; able to visualize what others cannot visualize (visionary); able to produce innovative ideas and implement them and can bring all these together to be socially and economically productive. Entrepreneurship is not specifically business but business can be part of it. Subsequently, integrating D&T with Entrepreneurship allowed learners to visualize the potential of their local materials and resources and how their local markets operate.

CAP 2009 appreciates that leaners' have different personalities and interests. CAP 2009 expects teachers to be sensitive to the nature and behaviour of each learner and align the teaching methods towards each learner's preferred method of learning. The preferred method of learning is determined by the nature/personality of the learner. Moreover, the teacher is expected to identify the learner's area of interests and talents, and facilitate and nurture those areas for the learner's survival needs.

13.7 Teacher's Role

The teacher's role has been changed by the Curriculum and Assessment Policy (CAP) 2009. The teacher is no more the conveyor/source of knowledge but is expected to facilitate according to the guidance of the syllabus, to nurture the skills, talents, attitudes, and values of the learners.

At the secondary level teachers are specialists in their disciplines. In Creativity and Entrepreneurship (C&E) some teachers have specialized in Business Education, ICT, Home Economics, and Design and Technology (Technical Subjects). In some schools, all specialists are available while in most schools only a Business Education teacher is available. Teachers in schools are expected to plan together and add the value of their specialization to the project, assign each other tasks, and time to teach to realize the project.

The syllabus prescribes the projects, and teachers and learners agree on themes to do to fulfill the project. The teachers, therefore, decide on content (Learning Outcome in the syllabus) and how much of it and from which discipline to be included to realize the project.

Teachers articulated that the expectations of the policy are fine depending on the focus to achieve the dual-purpose of the D&T integrated with Entrepreneurship. However, they expressed their challenges in achieving those expectations. Firstly, they pinpointed that the teacher–pupil ratio (1:40 and more) prevents them from giving each learner special attention since the curriculum prescribes that they should identify the talents and abilities of each learner and address them differently as learners are different. Secondly, they voiced the mismatch in the way they were trained (discipline orientated) and what they are expected to do (transdisciplinary).

They articulated that lack of skills and knowledge to teach and assess D&T integrated with Entrepreneurship syllabus is mainly because it is transdisciplinary, and most teachers were not trained in some disciplines within Creativity and Entrepreneurship (C&E).

Teachers also pointed out that facilitating the class to identify that each learner can relate the content with the world outside school (industry/the world of work) is time-consuming and not easy to determine when achieved compared to what they were used to, which is teaching learners to pass examinations. They further highlighted that it is even more difficult because they are expected to relate school with the world of work and on top of that facilitate and teach learners to pass examinations. Therefore, implementing the dual-purpose curriculum is challenging.

Teachers pinpointed limited places (industries, designers, artists, etc.), where learners can learn outside the classroom and the available few are more inclined to duplicate products rather than engage in designing. An example of the clothing factories in Lesotho was cited.

On the artists' side, they use indigenous knowledge which is not easily transferred/shared as the artist does not use sketches or drawings to share his/her ideas. Instead, the artist conceives an idea and makes an artefact and a learner should just watch the process. This adds to limited places where learners can learn outside school. Basotho hats (mokorotlo) are typical examples.

National Curriculum Development Centre (NCDC) personnel trained pilot teachers on the objectives and purpose of the CAP 2009, interpreting the syllabus and recommended teaching and learning methods, but teachers claimed that the time was not enough. Teachers expressed that the Curriculum and Assessment Policy (CAP) 2009 is making their role more demanding as they were trained in Universities and Colleges for years on the traditional subjects, not the integrated version (learning areas) brought by CAP 2009.

Conversely, teachers realized that learners are exploratory, and may vary their choice of materials. They can make "mokorotlo" with grass and the very same "mokorotlo" with the cloth. Learners are even more prone to reuse or recycle material to make other interesting products. For example, they use out-dated calendars for bracelets and earrings. Learners also share their artefacts on social media and that allows them to sell more products even to people who are not in their proximity. Social media also allow learners to make money by being invited to share their skills and creativity with other groups and platforms which are interested in artefact production. These issues allow learners to be productive and influence old/out-dated artefacts by artists while they further their education.

Teachers noted that C&E is offered in a practical approach that utilizes projects, themes, and scenarios that are familiar to the immediate environment of learners. Therefore, the approach allows learners to be more exploratory with materials in their environment; methods of advertising their artefacts and usage of digital technology. Consequently, allows learners to identify the strengths and weaknesses of the local economies and give them leverage on how they can venture or improve those economies. However, the same teachers were quick to point out that the digital technologies and are far-fetched to them and pose a challenge when they must facilitate and assess the learners.

All teachers observed used local materials in their classes, there were different artefacts from Grade five to eight depending on their local materials and resources. In one school learners produced stirring rods made of aloe agave, and bracelets and earrings made from paper and wire. On Friday afternoons, Grade seven learners would go to the main road to sell their artefacts produced in the class. They had fixed prices for their artefact throughout the month but at the end of the month, the prices increased. The money collected from sales was saved to help orphans in the school.

Learners from the same school organized an event at school where they displayed all their artefacts, performed music, and drama. They performed drama of one book which is on their syllabus to extend that they were requested in other schools to perform. They also invited parents and the community to sell their products. Learners and parents were also taking photographs of the artefacts to display on social media to show friends and advertise.

13.8 Expectations on Learners

Learners are expected to relate what they are learning in the classroom to their immediate and global environment specifically at the secondary level. Herbert Spencer the British positivist philosopher, sociologist, and educational reformer once said the aim for education is not knowledge but what knowledge is of most worth is to act it out (Liu et al., 2017).

D&T learners should be enabled to utilize skills, knowledge, and attitudes in their community, not just talk about D&T. The notion of Full Circle Learning (FCL) is relevant here, where it is recommended that what is learned in school should be practiced in the communities of those learners.

CAP 2009 in concurrence with Herbert and FCL has a vision that life challenges are better addressed through simultaneous application of concepts from different disciplines, hence the integrated version of the curriculum. Consequently, the aim of D&T with Entrepreneurship is to nurture learners to be vigilant to opportunities in their communities (local and globally) and utilize those opportunities. This envision learners to be economically productive and exhibit good values and attitudes as part of the society while also furthering their education.

There are Learning Outcomes (LOs) which learners are expected to achieve so that they visualize how the immediate environment operates. As early as Grade five, learners are expected to solve problems in their community and in school. For example, design signs and symbols which are currently not available in the schools and communities to simplify navigation and reduce the risks in their school area/society. They can place signs and symbols to show for an example the staff room, parking sites, and library, while in the society they can show things like the chief's place (Moreneng); risk areas like directions of crossing in a river which keeps on changing depending on how the sand has shifted in the river. In the process of designing they:

- Learn properties of the materials to erect signs and symbols
- Compare the font sizes and investigate colours and visibility for placement
- Learn about different consumables and tools (paintings, cloth, tinplate, steel, plastics, paper, and brushes)
- Explore and become cautious of the cost of material and time they spend designing
- Take note of the durability and size of their artefact
- Take note of the weather conditions and placement of their artefact
- Learn to negotiate and communicate the importance and placement of their sign with authorities of the community.

As learners work on the LO's, they are already translating what they are learning into what they would apply beyond the classroom level thus responding to society's needs. Issues, like buying materials, determining the time spend on the artefact, and negotiating where to place their artefacts in the community, are activities of concern in the occupation where the other purpose of D&T is focussed. However, teachers pinpointed that the projects are time-consuming and are challenging to assess. The practical work is not always fitting into double lessons (1 h 20 min) which is the maximum time allocated for a lesson (Evaluation of Secondary Schools Curriculum Diversification Programme, 1993). Therefore, learners must do extra time to finish or sometimes skip lessons from other learning areas to complete D&T projects.

13.9 Strategies to Improve Teaching and Learning of D&T with Entrepreneurship

When internalizing the strategies related to teaching and learning of D&T an important question is a purpose for teaching D&T with Entrepreneurship. The purpose is dual: to allow learners to further their education and allow them to get into the world of work with ease.

The strategies will be summarized in a table and thereafter will be detailed. Strategies are both applicable in the Lesotho context and other international contexts of D&T.

The issues that teachers should understand as they influence strategies to improve teaching and learning of D&T:

- Teachers should understand the purpose and the aim of the D&T from the policy level
- Teachers should be able to discover the value and strength of the subject as portrayed by the education system, e.g. is it an elective or compulsory subject, are teaching materials, refresher courses, and funding prioritized for the subject.
- Teachers should be able to understand how society visualizes the value and strength of Design and Technology (D&T), e.g. do they visualize it as the subject to help their children pursue their dreams (Table 13.1).

STRATEGY 1: Teachers should present lessons and designs in an open-ended way portraying real-life contexts so that creativity, exploration, and problem-solving skills can be triggered and enhanced. Teachers should not facilitate lessons in a closed manner that is subject, and examination orientated and unrelated to the learners' immediate world (Hills, 1998).

STRATEGY 2: Firstly, there should be collaboration among teachers and thereafter, between teachers and the world of work. Teachers should be willingly able to learn from others who are successful and gurus in the field. The details of how collaboration should be done between teachers and with the industry should be part of the training of teachers in colleges.

Teachers in schools need to be constantly in touch with the designers and technological communities, facilitating the effective implementation and understanding of technology. For example, secondary schools can ask companies to present the ideas they want to implement and those are given to learners as projects or invite experts to come and share their experience with learners. The companies in return get a certain percentage of tax exemption as an incentive to collaborate with schools.

Table 13.1 Summary of Strategies and their intention

Strategy	Intention
1. Present designs in an open-ended manner	Enhance creativity, exploration, and problem-solving skills
2. Collaboration among teachers and with the world of work	• Understand and appreciate the evolution of technologies • Present what is done in school to the outside world and get feedback • Invite experts to share the recent practices with teachers and learners
3. Incentives to encourage the diffusion of skills from industry to schools and vice versa	• To motivate both learners and the industry for better productivity • To allow learners to visualize their value in society and what they can contribute • In return the motivation encourages creativity, exploration, and problem-solving skills, therefore, makes it easy for a teacher to implement open-ended designs
4. Observe learners' abilities and be patient in nurturing and improving their weaknesses	• Improve the investigative nature of the Design and Technology • Know the learners
5. Identify personality, abilities, and interests	• Simplify identification of career paths or field of study at tertiary levels

STRATEGY 3: Incentives to encourage the diffusion of skills and knowledge from industry to schools and vice versa. In Lesotho education services, charitable activities, and aid projects are tax exempted (Value Added Tax ACT, 2001). There can be Design fairs at primary and secondary levels where both school and community identify problems and learners produce ideas to solve the problems.

Thereafter, the best solution which solves the problem well can be offered financial support where it can be reproduced. In that way, learners can be supported in their understanding of recent processes, characteristics, philosophy, and content of technology together with recent needs of the market (Impedovo, Ginestié & Williams, 2017).

In Lesotho, this happens regularly in higher education, like in an instance when a Limkokwing University of Creative Technology (LUCT) learner designed a blanket for the King's birthday. Therefore, with the introduction of incentives and a vision to improve education, the idea can trickle down to secondary and even to primary levels to enhance and nurture talents at a tender age.

STRATEGY 4: The teacher should know his/her students. Thus, the teacher should be vigilant in identifying learners' abilities and assist to improve the weaknesses of the learners. The teacher should know the behaviour and the competences the Design and Technology subject intends to develop. Table 13.2 can help the teacher to observe the behaviour of learners and match them with the intentions of the subject.

D&T with Entrepreneurship is observed as an investigative subject that helps learners identify resources around and use them profitably. Most importantly is

Table 13.2 The table below shows the D&T with entrepreneurship skills and the behaviour/actions to look for to identify a learner's skill inclination

D&T with Entrepreneurship skills	Behaviour/action
Passion	Manage distraction; set targets; do not give up; self-manage; argue or debate; become absorbed; take responsibility; practice and celebrate
Teamwork	Think together; consider others; listen; negotiate; discuss; empathise; agree
Risk-taking	Experiment; evaluate; present; hypothesise; change your mind; implement
Problem-solving	Identify and notice problems; question; analyse; consider; explain; adapt
Creativity	Notice; question; imagine; make links; explore; suggest; experiment; illustrate; model; simplify

(Creativity and Entrepreneurship Grade eight Syllabus, 2018)

intended to identify the passion of each learner, to induce and enhance teamwork, risk-taking, problem-solving skills together with creativity (novelty, value, and unexpectedness) as articulated by Maher (2006), Grace and Maher (2015). The teacher is expected to identify the ability of each learner on these D&T with Entrepreneurship skills: passion, teamwork, risk-taking, problem-solving skills, and creativity during class and project activities.

Taking passion as an example: A teacher should be watchful and observant to identify that a learner passionate about sketching can still sketch even when others are playing or doing other activities. When dealing with sketches, such a learner can look at various patterns, accuracy, even level of sketching by professionals and pace him/her to achieve a certain level within a specified time (set targets) and does not give up easily. The learner can do this without anybody monitoring (self-manage). When viewing and discussing sketching the learner can have narrations (argue/debate) depending on the uses, types, and styles of sketches and become absorbed in such debates. When there is an exhibition or anything which can use sketches, that learner will be the first to sketch the drawings for adverts (take responsibility). When the sketches did not meet the expectations the learner keeps sketching (practice). When the learner has met the expectations he/she tells the peers even post sketches on social media for more people to see his/her potential (celebrate).

Therefore, the teacher is expected to observe the behaviour, to nurture and introduce each learner to more work that is related to his/her behaviour. The teacher is also expected to encourage the learner in other behaviours in which the learner is weaker.

It is through several projects and activities that a teacher will realize the inclination of each learner. In Lesotho there is a profile for each learner which a teacher is expected to complete, to indicate the inclination of the learner. However, the process has not been utilized as planned because many teachers still believe in the summative examination as the representation of academic achievement, moreover, teachers claim that monitoring and usage of such profiles were not clearly clarified to them.

There are around nine or more disciplines within the Creativity and Entrepreneurship (C&E) learning area of which D&T with Entrepreneurship is one of them. Consequently, the teacher must observe where a learner shows more passion, talents, and creativity within the disciplines building C&E learning. This allows visualizing which areas a learner can specialize in when furthering their education.

STRATEGY 5: Identifies personality, abilities, and interests of learners to help in the field of study to follow or career. Besides using the table above, for a teacher to be able to identify and match the learners to their capabilities, talents, and passions, Holland's six modal of personality can be used. The six modal of personality consists of Realistic; Investigative; Artistic; Social; Enterprising; and Conventional (RIASEC). Each mode or personality has its specific identity of talents, interests, and capabilities that can be matched to a learner's personality. John Holland worked as a classifier of people according to their roles in Army and discovered that people consist of one or more personalities. He used key terms/typologies to fit a person's personality and tasks, career, or role. Such key terms for example are differentiation and consistency. Differentiation is how well a person suits another personality and the person's interests. Consistency is how well a person demonstrates/matches the actions of one or two close personalities even when the task or environment are different (Holland, 1992, 1997).

The six modes of personality can help teachers identify learner's nature/character, match it to what a learner can do, choose, like, or interests. They can also guide on careers a learner can follow; the type of courses a learner can pursue when furthering studies or the type of environment a learner can work at (MU Career Center, 2010). The teacher can identify the personality/nature of a learner during open-ended designs where learners express their passion, interests, and ability to realize a project in the C&E learning area. Thus, a teacher can realize whether a learner is Realistic (Doer); Investigative (Thinker); Artistic (Creator); Social (Helper); Enterprising (Persuader), or Conventional (Organizer) or has numerous personalities during the making of an artefact.

There are numerous actions/behaviours that build each personality/nature and mostly more learners can fit in different modes. Therefore, a variety of activities for longer period is necessary because one mode a learner is mostly inclined towards will be determined. A teacher needs to identify those actions from when a learner starts to design; up to artefact making and in extra-curricular activities to observe the personality they match. The teacher also need to use differentiation, vocational choice, consistency, congruence, and other typologies of John Holland to verify the inclination of the learner's personality. The importance of matching learners' personality with career or field of study is to increase efficiency and effectiveness of a learner with less motivation to a corresponding field of study which will lead to a job satisfaction and increased/higher achievement (Holland & Gottfredson, 1976).

13.10 Conclusion

D&T in Lesotho is about artefact production, artefacts relationship with its environment, and artefact evaluation, while Entrepreneurship is the state of mind where a person has a passion; can visualize what others cannot visualize (visionary); able to produce innovative ideas, implement them, and bring all these together to be socially and economically productive. D&T by its design process content encapsulates characteristics of Entrepreneurship. Therefore, integrating it with Entrepreneurship deepens and clarifies the main concepts.

The Creativity and Entrepreneurship learning area aims at infusing Entrepreneurship into practical skills. This is done to realize how the content in school can improve the social and economic lives of learners in their communities. Therefore, Curriculum and Assessment Policy 2009 has shifted a focus from only summative examinations as the tool to measure academic achievement and has reinforced it with Continuous Assessment. The policy also recognizes that production, work-related competencies, and talents are nurtured at an early age.

Despite these efforts by the CAP 2009 most officials, teachers, and the public at large are still looking at the summative examination as the goal for academic achievement. There is still prioritization of the subjects (English, Mathematics, and Science) which were prioritized by colonial education and financial support from other international organizations is directed towards them. D&T with entrepreneurship, and other practical subjects, are taught as electives, not compulsory subjects and offered in few schools even though the national strategies suggest them as necessary for poverty emancipation and self-reliance.

D&T with Entrepreneurship is successfully implemented by some teachers while others are unable to do so. There is a need for further research to determine the personality and background of teachers who are implementing Design and Technology with Entrepreneurship successfully, to have the base for methodologies and strategies for teaching and learning of D&T with Entrepreneurship. There is also a need to review the programmes of teachers' training colleges and whether they inculcate collaboration skills; talents, and personality observation to their trainees besides the D&T knowledge and skills.

References

Biemans, H., Nieuwenhuis, L., Poell, R., Mulder, M., & Wesselink, R. (2004). Competence-based VET in the Netherlands: Background and pitfalls. *Journal of Vocational Education and Training, 56*(4), 523–538.

Creativity and Entrepreneurship Grade 8 Syllabus. (2018). *Ministry of Education and Training (MoET).* Maseru. Lesotho.

Curriculum and Assessment Policy (CAP) Framework. (2009). *Ministry of Education and Training (MoET).* Education for Individual and Social Development. Maseru.

Department for Education (DfE). (2013). *Design and technology programmes of study: National curriculum in England.* London: DFE-00192-2013.

Design and Technology Syllabus 0189. (2015). *Lesotho general certificate of secondary education*. National Curriculum Development Centre in Collaboration with Examinations Council of Lesotho. Maseru.

Evaluation of Secondary Schools Curriculum Diversification Programme. (1993). *Final report of world bank and government of Lesotho*. Cambridge Education Consultants, Cambridge UK.

Grace, K. & Maher, M. L. (2015). Surprise and reformulation as meta-cognitive processes in creative design. In *Proceedings of the Third Annual Conference on Advances in Cognitive Systems*. Software and Information Systems, UNC Charlotte, Charlotte, NC, USA.

Gretsinger, E. & Lorne, F. (1984). *Analysis of project*. IDA/700-LES-10.

Hill, M. A. (1998). Problem solving in real-life contexts: An alternative for design in technology education. *International Journal of Technology and Design Education, 8*, 203–220.

Holland, J. L. (1997). *Making vocational choices: A theory of careers*. Prentice Hall.

Holland, J. L. (1992). *Making vocational choices: A theory of vocational personalities and work environments* (2nd ed.). Psychological Assessment Resources.

Holland, J. L., & Gottfredson, G. D. (1976). Using a typology of persons and environments to explain careers: Some extensions and clarifications. *Counseling Psychologist, 6*, 20–29.

Impedovo, M. A., Jacques Ginestié, J., & Williams. J. (2017). Technological education challenge. A European perspective. *Australasian Journal of Technology Education*, 1–14.

Jackson, G. O. (Ed.). (2002). *Teaching design and technology in secondary schools*. London and New York. The Open University.

Jones, C., Penaluna, K., & Penaluna, A. (2019). *The promise of andragogy, heutagogy and academagogy to enterprise and entrepreneurship education pedagogy*. University of Wales Trinity Saint David, Carmarthen, UK.

Liu, Y., Li, K., & McLean, A. (2017). Practical Scientific Knowledge education based on Herbert spencer's "what knowledge is of most worth?" *EURASIA Journal of Mathematics Science and Technology Education, 13*(7), 4291–4299.

Maher, M. L. (2006). *Evaluating creativity in humans, computers, and collectively intelligent systems*. Design Lab University of Sydney.

MU Career Center. (2010). *Career and major exploration job search preparation after college planning diversity, student success center: Lowry Mall*. University of Missouri.

Stables, K. & Buck, L. (2019). Design and technology education. *An International Journal, 24*(1), 1–141 (Online: ISSN 2040-8633).

Value Added Tax ACT, (2001). *Lesotho Revenue Authority*. Retrieved November 10, 2020, from http://lra.org.ls/sites/default/files/2017-05/VAT%20ACT%20-%202001.pdf.

Van Aar, N., van Oenen, S & van Keulen, H. (2016) Cooperation between primary schools and technological companies: a matter of boundary crossing. In *PATT-32 Proceedings Technology Education for 21st Century Skills*. Netherlands.

Nthoesele Mohlomi taught Design & Technology for thirteen years, has B-Tech in Technical subjects, an Honors in Education and Masters in Urban & Regional Planning and persuing a PhD in Education. I have more than five years working experience at the National Curriculum Development Centre (NCDC), currently working as Senior Curriculum Specialist—Creativity & Entrepreneurship and leading the team that is developing Entrepreneurship Education with the support of the Economic Diversification Support Project and funding from AfDB. The author of Grade 6 and 7 Creativity & Entrepreneurship books which are used in all Lesotho Primary schools. In Higher Education I have been a part-time lecturer for a year in Lesotho College of Education (LCE) in the Technology department, currently part of the team that is facilitating the development of the apprenticeship strategy to be used throughout Lesotho and participating in the development of the Hospitality and Management curriculum in Lerotholi Polytechnic.

Chapter 14
Teaching Technology in a Play-Based Preschool—Views and Challenges

Pernilla Sundqvist

Abstract This chapter is based on studies that investigated technology education in preschool focusing on the content described and taught by the staff, how this content is taught and what children are enabled to learn through this teaching. Three methods were used to investigate this. First a questionnaire, then interviews and finally an ethnographically inspired perspective where data was generated from observations and interviews. Participants were preschool teachers and childcare attendants in Sweden. Departing from those studies, this chapter will provide a picture of what preschool technology education is to the participants of the study as well as what preschool staff find challenging when it comes to teaching technology. The results show that the view on preschool technology education is broad and varies between preschool staff. Two specific challenges were: what is included in the concept and the content area of technology, and how some specific content can be taught in the context of a play-based preschool. The last part of this chapter will address these challenges and try to provide some clarification and suggestions.

Keywords Preschool · Preschool teacher · Technology education · Views · Challenges

14.1 The Questions I Asked and Why They Are Important

For someone who is teaching technology, understanding what technology is, is essential to interpret and understand the curriculum's intentions for the subject. Previous research has shown that teachers have limited knowledge and confidence in technology (Jones et al., 2013). They are unsure about what to teach and how. This leads to the subject being taught differently among teachers depending on what they see as the purpose for the subject (see, e.g., Bjurulf, 2008; Klasander, 2010). There are at least two possible reasons for this. First, technology as a school subject has a

P. Sundqvist (✉)
Division of Mathematics and Natural Sciences Didactics, School of Education, Culture and Communication, Mälardalen University, Västerås, Sweden
e-mail: pernilla.sundqvist@mdh.se

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_14

relatively short tradition, meaning the teachers teaching the subject now may not have any experience from their own years in compulsory school to relate the subject to. Second, the subject has been vaguely defined, the purpose for the subject has not been clear (Hagberg & Hultén, 2005).

While the subject technology has posed challenges for teachers, in preschool the challenges concern teaching a subject at all as studies show preschool teachers have difficulties organizing and performing teaching around a planned content (see, e.g., Sundberg et al., 2016; Thulin, 2011). Looking back at the Swedish preschool's history, learning subjects and various content areas has not been an objective. The Swedish preschool, along with preschool in many other countries, has a long tradition of the social pedagogic approach (Bennett, 2005). Accordingly, focus has been on the child's wellbeing and social development, rather than on cognitive skills, which is the focus in countries adopting the pre-primary approach. During the last couple of decades, the mission for the Swedish preschool has gradually changed, with each revision of the curriculum focusing more on children learning specific subjects.

Today, the preschools' three pillars: care, development and learning are equally important. With the latest Education Act (SFS 2010:800) and curriculum (The Swedish National Agency for Education, 2018), the term teaching is applied to the preschool. This is something many among the preschool staff are uncomfortable with because they associate the term with education in school, rather than preschool practice (Jonsson et al., 2017; Sæbbe & Pramling Samuelsson, 2017). To preschool staff, preschool practice is a play-based practice, in contrast to education in school. And indeed, the preschool curriculum emphasizes and values play as a vehicle for learning, and this means children should be encouraged to play on their own, and play should be used to make teaching meaningful and fun.

In 2010 a revision of the curriculum (The Swedish National Agency for Education, 2010) included technology as a content area for the preschool. This means a practice that is adjusting to the new mission of teaching is also commissioned to teach a vaguely defined subject: technology. One can assume preschool teachers perceive a double challenge in this. To support preschools in this assumed double challenge, we need to know the current state of preschool technology education. This is what I investigated in my theses. In this chapter I will present results concerning the following questions:

1. What do preschool staff as a group view as possible content for preschool technology education?
2. What technological content is taught?
3. How is preschool technology education characterized by individual preschool teachers and childcare attendants?

14.2 How I Tried to Answer the Questions

Three sets of data were generated for the study: a questionnaire with 102 respondents, interviews with seven interviewees and an ethnographically inspired study, using observations and interviews, with two participating preschool units.

First, a questionnaire was sent out to preschool staff in one Swedish municipality. The questionnaire contained both closed and open-ended questions about how the respondents view preschool technology education. For example, questions posed were: *What do you consider technology education in preschool to be?* And *The revised curriculum assigns two goals to the teaching of technology as a subject. How will you be able to work with these goals in practice? Give suggestions for each goal.* The goals were provided in the questionnaire. Respondents were both preschool teachers and childcare attendants with varying numbers of years on the job and most with little or no training in technology education.

After analyzing the questionnaire data, seven participants from the questionnaire study were chosen for interviews. The participants were chosen to represent the variety among the respondents from the questionnaire study, in terms of age, working experience, training in technology education and views of technology education expressed in the questionnaire. Five preschool teachers and two childcare attendants were interviewed about how they deliver technology education at their respective preschools. Questions asked were for instance: *On a typical day at preschool, when do children encounter technology? How would you describe a successful technology learning/teaching situation from your practice? Are there any difficulties in working with technology in preschool?* Follow-up questions were formulated depending on how the participants responded.

Lastly, an ethnographically inspired study was performed using observations and interviews. At two preschool units, preschool staff were observed while teaching and interacting with children. The preschool staff observed were two preschool teachers at the first unit and at the second unit one preschool teacher and two childcare attendants. Both formal and informal interviews were also performed with the preschool teachers.

I will now describe how the data analyses were performed to answer the three questions posed in the previous chapter.

What Do Preschool Staff as a Group View as Possible Content for Preschool Technology Education?

To answer this question, data from the first two phases of data generation was analyzed. First questionnaire data was analyzed inductively resulting in a set of categories describing the content posed by the participants. The categories were then developed by sorting interview data into the categories. Interview data provided both clarification and additions to the content, allowing the categories to evolve. The result is a set of categories and subcategories describing the content posed by the preschool teachers and childcare attendants as suitable content for technology education.

What Technological Content is Taught?
More precisely, the question was, what of the technological content described in the questionnaire and interviews was actually taught in the two preschool units? It was found from the questionnaire and the interviews that the content for preschool technology education can be both broad and deep. Here, I wanted to see if all of this is taught. Data from the observations was therefore analyzed using the previously created categories as a framework. However, the results from the previous analysis included statements that did not describe a technological content or objective. For this analysis, those categories were excluded, because the aim was to see what technological content was taught in the preschool units.

How is Preschool Technology Education Characterized by Individual Preschool Teachers and Childcare Attendants?
This question was studied by applying a narrative analysis to the participants' descriptions of their technology teaching, in the interviews. Thus, each interview was analyzed separately focusing on what the participant emphasized concerning technology education, for instance, through repetition. The result presents how each participant characterizes technology education through their descriptions of what and how they teach technology.

14.3 What I Found Out

In this section the results are presented in relation to the questions posed above. The results answering the first two questions are presented together.

14.3.1 What Do Preschool Staff as a Group View as Possible Content for Preschool Technology Education? and What Technological Content is Taught?

Table 14.1 provides an overview of the categories created to present the content described by the preschool staff as appropriate for preschool technology education (first column). In the second column it is stated if the category was included for observation of the two preschool units. The third column presents if and how the content was observed to be taught.

As shown in the first column of Table 14.1, a broad range of technological content was described by the preschool staff, with a focus on technological objects and building activities. The categories include simple everyday activities, such as using cutlery when eating lunch, and building activities that have no purpose from the staff's point of view. They also include more complex content, such as exploring the adequacy of technological objects and materials, how technological objects and

Table 14.1 Overview of the results

Category	Includes a technological content or objective	Observed in the preschool units
Learning to handle technological objects	Yes	Children were encouraged to handle objects on their own, provided time to practice or instructed how to. Technological objects were, e.g., the computer tablet, the zipper in their jacket, and the hole puncher
Learning the application areas and adequacy of technological objects	Yes	E.g., by staff letting children try different tools for the same task and talk about which one was the best and why
Learning the purpose of technological objects	Yes	Not observed
Learning how technological objects and systems work	Yes	E.g., by staff talking about how the glue gun works. This content was only taught in response to some child's question
Building and creating	No objective described, therefore excluded from the observations	
Learning about materials	Yes	In creative activities, staff would provide lots of materials and sometimes talk to the children about their use or properties
Learning to build and create by practicing (learning building/creative techniques)	Yes	In creative activities staff would talk about why some method for creating/building something was better than another
Learning a specific content by building and creating	Not necessarily, excluded from the observations	
Solving a problem by building/creating a solution	Yes	Children were observed to solve problems in line with the technological design process, and encouraged by the staff in diverse ways, e.g., by staff helping the child to keep in mind the requested function or support the child in how to go about finding a solution

(continued)

Table 14.1 (continued)

Category	Includes a technological content or objective	Observed in the preschool units
Learning how something is produced	Yes	This was taught in terms of things produced by the children. The category included production of things like toilet paper and electricity. But observed was, e.g., the process of making gingerbread. This was taught by the teacher telling the children about the process from dough to completed cookie, while making gingerbread with the children
Learning what technology is	Yes	Not observed
Learning techniques	Not necessarily, excluded from the observations	
Learning natural science and other content areas	No, excluded from the observations	

systems work and what makes a stable construction. The study also shows that content addressing areas other than technology was described as technology education by preschool staff.

Much of the *technological* content was observed to be taught in the two preschool units; all except two categories. The ones not observed were learning the purpose of technological objects and learning what technology is. The absence of the purpose of technological objects was not so surprising considering it was only mentioned by two of the 102 respondents in the questionnaire study. In contrast, learning what technology is was emphasized as important by several respondents in the questionnaire study. However, at no time during the observations did I hear the staff use the word technology with the children.

14.3.2 How is Preschool Technology Education Characterized by Individual Preschool Teachers and Childcare Attendants?

In this section, I will present the different ways to characterize technology education that I found by analyzing the interviews from the preschool staff. Of the seven interviewees, two gave similar descriptions of their teaching therefore there were six ways to characterize technology education in preschool provided.

Technology education is using technological objects. This way of characterizing technology education means children are encouraged to use technological objects to learn how to handle them. It can be everyday objects like scissors, cutlery, the tap, the zipper in their jacket or a computer tablet and other information and communication technology (ICT). Regarding ICT, and specifically, the tablet, the interviewee regards it as technology education even when it is used for learning about for instance animals or mathematics.

Technology education is doing experiments. In this view technology and natural science are not separated, and "doing" natural science and technology equals doing experiments, often natural science experiments.

Technology education is developing abilities. Instead of technological content, this view emphasizes abilities. It can be technological abilities or more general abilities. Technological abilities include, for instance, creativity and collaboration in construction play. More general abilities like independence are emphasized as the objective for why children should learn how to handle technological objects.

Technology education is technological objects and systems in the children's environment. Here, children should learn about objects and systems and how they work. Objects and systems in the preschool environment are used as teaching materials and things that are temporarily located in the preschool environment, like the garbage truck or maintenance of the district heating system are made into learning objects by seizing the moments when they present themselves.

Technology education comes naturally in children's free play. This way of characterizing technology education means children are believed to learn technology on their own if they are provided with adequate materials. Therefore, the preschool teacher does not teach, but organizes the environment to enable exploration of technology.

Technology education through, and departing from, digital technology. In this view, digital technologies are a crucial factor in teaching and in technology education. The tablet, sometimes connected to a projector, is used to find out how things work or to show video clips to inspire children in different ways, for instance, to develop or imitate a construction.

The results show some critical issues to address about how technology education is understood. In the next section, I will discuss how different ways of understanding the subject affect what children are able to learn from the teaching. I will also provide some examples of how technology education can be performed in the context of preschool to promote children's learning around different technological contents.

14.4 How This Might Be Used to Improve Teaching and Learning

In the first section of this chapter I described an overarching aim for the study: to investigate the current state of preschool technology education to provide support in the challenges preschool staff perceive. Of course, the study found many positive things that are done well. However, in this chapter I have chosen to focus on the things that are challenging and affect education negatively and to provide clarification and suggestions to improve preschool technology education further. The study has found two main challenges that negatively affect the teaching of technology. The first challenge is that it is not clear to all preschool staff what technology is and what should be taught in preschool when it comes to technology. The second challenge is how to teach some specific technological content in a play-based preschool. Below I will address these two issues.

14.4.1 What Preschool Technology Education is, and What It is Not

The categories in Table 14.1 and the different ways to characterize technology education show preschool staffs' different views on technology and technology education and how these views affect what children can learn. The results show at least three problematic issues. Issues that will affect teaching negatively. To improve teaching, the teacher need's a better understanding of technology and technology education. Therefore, in this section, I will provide examples of what technology and technology education is and what it is not.

The first problematic issue is that some preschool staff are unsure about what technology is. They mix-up technology with other content areas, like science, and they view the use and learning of techniques as technology. Of course, mastering some techniques is necessary for handling and constructing technological objects. However, some preschool staff also include techniques that have nothing to do with technology, such as climbing a rock or jumping. The reason for this mix-up is simple. In Swedish language, technology and technique are the same word: "teknik." Regarding the mix-up with science, it is not unusual that technology education is equated with doing experiments and these experiments are often focused on science rather than technology (Sundqvist, 2016). However, experiments are used as a method both in technology and in science but in different ways, they have different aims (Norström, 2015). In technology the aim is to "find out how to achieve certain practical ends" (Hansson, 2013, p. 22) by examining "the relation between design characteristics and function-related outcomes" (Norström, 2015, p. 323). This differs from the purpose of natural science experiments, which is to understand nature.

For a preschool teacher it is of course important to have a conceptual knowledge about technology to teach it. To separate technology from science a simple rule is that while science regards nature, technology is man-made. That means science seeks to understand, explain, and predict natural phenomena. Technology, on the other hand, studies and creates objects and systems to address human needs. A fundamental difference is thus that technology is a product of human activity, while nature exists regardless of what people do. However, the concept of technology is not limited to the objects and systems created by humans, it is broader than that. DiGironimo (2011) provides a broad description of technology. She includes the objects and systems created by humans, such as machines, internet, clothes, kitchen appliances, furniture and so on, and the creation of these objects and systems. The creation is described as a design process and includes the skills and knowledge people need and use to design and create technology. DiGironimo also emphasized that because technology is a human activity it is affected by our human values and assumptions. Lastly, she acknowledges the historical aspect of technology. The way we use, create and understand technology today differs from how we have used, created and understood technology during various times in history. While the technology we create is affected by the time we live in, we are also affected by technology in how we live, work and socialize.

The second problematic issue regards how technology is addressed in teaching, as a goal or means. For a teaching activity to be regarded as technology education, technology needs to be the goal. In the activity with Pippi Longstocking described below, technology is addressed as a goal. The children get to explore and discuss technological objects with the aim to develop their knowledge in technology. If technology is treated as the means, the goal can be anything (science, math etc.) but the goal is reached by using technology. For instance, building activities can be used as means to learn math or to collaborate. It is also common for preschool staff to let children use the computer tablet to learn about animals, math, language etc. For example, the tablet's camera and magnifier can be used to observe insects and learn about their structure. This is a good example of how to use the tablet as a tool for learning. However, in the case of observing insects children learn biology, not technology. Thus, it is not technology education.

This leads to the third problematic issue, which is that preschool staff acknowledge all use of information and communication technology (ICT) as technology education, even when it is used to learn other things. And indeed, because ICTs are considered as tools for learning in preschool, when they are used, they are more often used for other things than for learning about the technology itself. This research revealed that common applications for ICTs are to learn about animals or math, write a story or document an activity or a child's work.

So, for the education to be considered as technology education, technology-related learning outcomes need to be the goal. That means exploring, investigating and creating technological objects and systems. Children can explore different ways of using a technological object, investigate the construction of the object and discuss pros and cons of the construction from different perspectives (environmental, economic, user friendliness, historical etc.). When it comes to creating technology, children need to have some specific skills, such as handling tools. Training these skills can also be considered as preschool technology education.

Lastly, the education should also include learning what the concept of technology means and includes. This is important for several reasons. One is that we need more adolescents to apply for technical programs and choose technical professions. However, if they do not know what a "technical program" is because they do not know what technology is, they are unlikely to apply to such a program. For children to view technology as something they can be interested in, understand and work with the concept of technology need to be developed. The view many people hold, that technology is objects, primarily digital technological objects such as computers, mobile phones and tablets, suggests that technology is something complex and difficult, something only experts can understand (Benenson, 2001). Therefore, preschool needs to aim at broadening children's concepts of technology. The objects identified as technology need to also include simple and old technology such as clothes, furniture and household appliances. Further, technological processes and people's role in the development of technology need to be acknowledged. To view technology as something that concerns solving a problem, that the problem can have several solutions and that people are the ones who both create the solutions and decide if the solutions are good enough can give children a chance to view technology as something for them, something they can have competence for.

14.4.2 To Teach Technology in a Play-Based Preschool

The research showed that two important technological content areas are problematic for preschool staff to teach. The content addressing how technological objects and systems work was observed to be taught only when children requested it–when they showed specific interest or explicitly asked questions about how something works. Teaching of the content was never observed to be initiated or planned by teachers. The other content that seems problematic to teach is what technology is, which was not observed to be taught at all. In another study preschool heads discussed the use of the word technology and concluded it is not often used in everyday language with the children in preschool (Sundqvist & Nilsson, 2021). When the word "teknik" is used, it is in the meaning of technique. Preschool staff find it difficult to include the word in common conversations with children, and since they do not want to teach children, using a traditional meaning of teaching (Jonsson et al., 2017; Sæbbe & Pramling Samuelsson, 2017), they do not use the word. The same can be assumed for how technological objects and systems work. How something works often needs an explanation. This can be perceived as traditional teaching—a school-like way of teaching—if it is initiated by a teacher. To overcome this, I will try to show how teaching of this content and a play-based approach can come together.

Indeed, teaching in a play-based preschool is different from teaching in school. Teaching in preschool should be playful, meaningful and depart from children's perspectives (Björklund & Pramling Samuelsson, 2018). However, this can be done in many ways. First, what happens in preschool can be either child-initiated or teacher-initiated. Play-based teaching can originate from either the child or the teacher. Further, teacher-initiated teaching can be either spontaneous, by capturing a given opportunity at the moment or planned. What is important, if the teacher has planned a teaching activity, is that the teacher can capture children's attention and interest them in the planned learning object (Björklund & Pramling Samuelsson, 2018). This can utilize children's inner motivation to explore and learn. Being guided by an inner motivation rather than by the teacher is one way that children define play (Øksnes, 2011).

In the following I will describe a teacher-initiated planned situation where the teachers wanted the children to investigate a technological object, including the two technological content areas described above, and how they organized the situation to promote the children's interest to do this.

On the floor, in a preschool unit for children aged three to five years, sits 15 children and one preschool teacher. They are waiting for a visit. Suddenly, the door opens and Pippi Longstocking enters. It is another teacher who has dressed up as Pippi. Pippi greets the children and announces she just came back from a walk where she found something interesting. As everyone knows, Pippi likes to collect things she finds outside, things people have dropped or thrown away, and find new ways to use them. This time she found something she does not know what it is. The children can help her. She shows the children a suitcase she carries. It has the word Technology written on each side. Pippi explains that things people have made are called technology and those are the things she puts in the case. She sits down and starts to open the case. The children are curious and look to see what is in the case. Pippi takes out a hand crank whisk. "Nice, right?," she says. "What do you think this is?" A child points at the whisks and says it looks like the thing you use to whip cream. Another child yells they have one of those here at the preschool. She has seen one of the staff using it in the kitchen. She asks if they can fetch it and compare it to Pippi's object.

The sequence continues with the children investigating the hand crank whisk and comparing it to the electric hand mixer the teacher fetched from the kitchen. They establish the two objects are used for the same purpose and discover similarities and differences between the two. They both have whisks that look the same and rotate, but how the rotation is accomplished and how the objects are handled differ. The children's investigation of the two objects is driven by their own curiosity, which the teachers have created with their staging of the situation. By using a character from a children's book, a character perceived as funny and crazy, the teachers manage to engage and interest the children. In a fun and playful way, the children are given a simple explanation of the word technology, and they explore and discuss the use, function and design of two technological objects.

The description of the word technology provided in the teaching situation is quite simple—objects people create—and the children are provided with only one example, the hand crank. However, the visit by Pippi can be a recurring activity. If different objects are unpacked from the "technology case" each time the children will gradually be able to broaden their understanding of what a technological object is. However, I stated earlier that technology is not limited to technological objects. Technological processes like problem-solving and construction also need to be acknowledged as technology. The results of this study show children engage in such activities in preschool. So, when talking to the children about these activities, the preschool teacher can apply the word technology to them, thereby describing them as technological activities and broadening children's concept of the word technology.

14.5 Conclusion

This research has shown that one main challenge with teaching technology in preschool is the staff uncertainty of what technology is and what technology education in preschool is. To understand a concept, like technology or technology education, you not only need to know what the concept includes but also what it does not include (Marton & Tsui, 2004). For the reader to better understand technology and technology education, I have provided examples of what technology education is and what it is not. To further develop this understanding the reader might use their own practice and discuss it with their colleagues. I suggest documenting technology teaching sequences and discuss whether they teach technology, or if they teach something else. Use the definitions and examples I have provided in this chapter and complement if necessary with other literature.

As an example, we did this in a participatory research study, performed as a research circle. Myself and two colleagues worked with two groups of preschool staff with the aim to develop the staff knowledge and understanding of technology education in preschool. First, we all read a chapter from my licentiate thesis (Sundqvist, 2016) in which the content areas of technology education presented in Table 14.1 are further described with several examples. We also read a chapter (Sjöberg, 2004) that explains and elaborates on the differences between technology and natural science. Second, the preschool staff were asked to observe their practice and document situations where they thought some technology teaching and/or learning was happening. Then, they brought their documentation back to the group and together we analyzed them using the literature we had read. We discussed whether the situations addressed technology, and if so, what aspects of technology. In the evaluation of the study, the preschool staff said this procedure was very fruitful for developing their understanding of what technology education in preschool can be.

Of course, you do not need a researcher to lead this kind of work. You can do it together with your colleagues. When you feel confident with what technology is, which aspects or contents relating to technology are taught in specific activities, you might move on to discussing *how* to teach different content areas of technology. Depending on your pedagogical approach the “how”-question will have different answers. Think about how you teach areas you feel more confident with and discuss how you can transmit pedagogical strategies from that teaching into technology teaching. In your work team, you probably have lots of experiences from teaching other subjects that may help you in discussing how technology education can be performed in your specific context.

References

Benenson, G. (2001). The unrealized potential of everyday technology as a context for learning. *Journal of Research in Science Teaching*, *38*(7), s. 730–745.

Bennett, J. (2005). Curriculum issues in national policy-making. *European Early Childhood Education Research Journal, 13*(2), 5–23.

Björklund, C., & Pramling Samuelsson, I. (2018). Undervisning, lek, lärande och omsorg—förskolans hörnstenar. [Teaching, play, learning and care—preschool's cornerstones]. In S. Sheridan & P. Williams (Eds.), *Undervisning i förskolan. En kunskapsöversikt.* Skolverket.

Bjurulf, V. (2008). *Teknikämnets gestaltningar: En studie av lärares arbete med skolämnet teknik.* [*Construing technology as school subject: A study of teaching approaches*]. Doctoral thesis, Karlstad University, Karlstad.

DiGironimo, N. (2011). *What is technology? A study of fifth and eighth grade student ideas about the Nature of Technology.* Doctoral thesis, University of Delawere, United States.

Hagberg, J.-E., & Hultén, M. (2005). *Skolans undervisning och elevers lärande i teknik—svensk forskning i internationell kontext.* [*School's teaching and pupil's learning in technology—Swedish research in an international context*]. Vetenskapsrådet.

Hansson, S. (2013). What is technological knowledge? In I.-B. Skogh & M. J.de Vries (Eds.), *Technology teachers as researchers* (pp. 17–31). International Technology Education Studies, Sense Publishers.

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.

Jonsson, A., Williams, P., & Pramling Samuelsson, I. (2017). Undervisningsbegreppet och dess innebörder uttryckta av förskolans lärare. [The teaching concept and its meanings expressed by the teachers of preschool]. *Forskning om undervisning och lärande, 5*(1), 90–109.

Klasander, C. (2010). *Talet om tekniska system: förväntningar, traditioner och skolverkligheter*. Doctoral thesis, Linköpings universitet, Norrköping, Sweden.

Marton, F., & Tsui, A. B. M. (2004). *Classroom discourse and the space of learning*. Erlbaum.

Norström, P. (2015). Technological experiments in technology education. In M. Chatoney (Ed.), *Plurality and complementarity of approaches in design and technology education: PATT29 conference proceedings* (pp. 322–327). École supérieure du professorat et de l'éducation, Aix-Marseille Université.

Øksnes, M. (2011). Lekens flertydighet: om barns lek i en institutionaliserad barndom. [The multifaceted play: on children's play in an institutionalized childhood]. Liber.

Sæbbe, P.-E., & Pramling Samuelsson, I. (2017). Hvordan underviser barnehagelærere? Eller gjør man ikke det i barnehagen? [How do preschool teachers teach? Or do they not teach in preschool?] *Tidskrift för Nordisk barnehagsforskning, 35*(14), 1–15.

SFS 2010:800. *Education act.* Department of Education.

Sjöberg, S. (2004). *Naturvetenskap som allmänbildning.* [Natural science as general knowledge]. Studentlitteratur.

Sundberg, B., Areljung, S., Due, K., Ekström, K., Ottander, C., & Tellgren, B. (2016). Understanding preschool emergent science in a cultural historical context through Activity Theory. *European Early Childhood Education Research Journal, 24*(4), 567–580.

Sundqvist, P., & Nilsson, T. (2021). Preschool heads' perceptions of technology and technology education. *Techne Serien—Forskning i Slöjdpedagogik Och Slöjdvetenskap, 28*(2), 418–424.

Sundqvist, P. (2016). *Teknik i förskolan är inte något nytt, men idag är vi mera medvetna om vad vi kallar teknik: Personalens beskrivningar av teknik som innehållsområde i förskolan.* [*Technology in preschool is nothing new, but today we are more aware of what we call technology. The staff's descriptions of technology as content area in preschool*]. Licentiate thesis, Mälardalen University, Västerås, Sweden.

The Swedish National Agency for Education. (2010). *Curriculum for the preschool Lpfö 98, Revised 2010.* The Swedish National Agency for Education.

The Swedish National Agency for Education. (2018). *Curriculum for the Preschool, Lpfö 18*. The Swedish National Agency for Education.

Thulin, S. (2011). *Lärares tal och barns nyfikenhet: Kommunikation om naturvetenskapliga innehåll i förskolan.* [*Teacher talk and children's queries: Communication about natural science in early childhood education*]. Doctoral thesis, Gothenburg University, Gothenburg, Sweden.

Pernilla Sundqvist holds a doctorate of philosophy in education and is senior lecturer at Mälardalen University in Sweden where she teaches primarily in the preschool teacher program. In her thesis she studied preschool teachers' views on, and teaching of, technology education. She has a background as a preschool teacher and her continuous research interests involve collaborations with practitioners where research and education develop and improve in a common process, benefitting both partners equally. Recent work includes a collaboration project aiming at improving technology education at the preschools in a Swedish municipality while also contributing to the research base in the field of early years technology education.

Chapter 15
Applying a Culturally Responsive Pedagogy to Promote Indigenous Technology in Teaching Design Skills

Richard Maluleke and Mishack T. Gumbo

Abstract This chapter explores the strategies that are related to culturally responsive pedagogy (CRP) to facilitate the integration of indigenous technology in teaching design skills in Technology Education classes. Technology teachers are advised to consider indigenous pedagogy (IP) as that will accommodate learners from both indigenous and non-indigenous contexts; curricula and teaching have a colonial history of excluding indigenous knowledge. Indigenous pedagogy is based on experiential and practical learning which is dominant in indigenous communities. It is therefore a pedagogy through which the young ones are taught and shown how to perform tasks in their localities. The specific indigenous pedagogy framing the discussions in this chapter is culturally relevant. This study revealed that culturally relevant pedagogy has a role to play in the teaching of design skills in Technology Education, hence it can help Technology teachers to make the learning of Technology relevant to indigenous learners who are mostly switched off from learning by the conventional pedagogies. The findings of the study revealed that the use of CRP can promote the integration of indigenous knowledge and artefacts in the teaching of design skills. The findings suggest a review of the current design method to accommodate indigenous as well as non-indigenous learners. Therefore, we suggest an indigenous technology-based design process (ITbDP) which can transform the current conventional approaches in the teaching of Technology.

Keywords Technology education · Indigenous technology · Indigenous pedagogy · Culturally relevant pedagogy · Design skills

R. Maluleke (✉)
Nkone Maruping Primary School, Johannesburg, South Africa

M. T. Gumbo
University of South Africa, Pretoria, South Africa
e-mail: Gumbomt@unisa.ac.za

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_15

15.1 The Research Questions and Their Importance

The research questions being addressed in this chapter are as follows:

- How can culturally relevant pedagogy (CRP) be used to make the teaching of design skills in Technology Education not to non-indigenous learners only but to indigenous learners as well?
- What are the teaching strategies which can support CRP in the teaching of design skills in Technology Education?
- How can the current design process be re-orientated towards accommodating CRP in Technology Education?

The South African Technology Education curriculum includes indigenous technology in line with the human rights principles within the broader curriculum. However, Technology teachers have not yet taken full advantage to integrate indigenous technology and resources in teaching design skills. Technology teacher training has also not helped teachers in this regard. We suspect that teachers do not know how to teach Technology from an indigenous perspective. Therefore, answering the above questions can contribute knowledge about how to use CRP to integrate indigenous technology in the teaching of design skills. Indigenous technological skills can play a pivotal role to enhance the capabilities of learners to design technological prototypes. Technology learners should be equipped to make artefacts to prepare them to fit in the job market as future engineers, artisans, architects, etc. (Department of Basic Education [DBE], 2011). Gumbo (2015) states that a re-contextualised Technology teaching that integrates indigenous knowledge can produce professionals with the design skills that they need to actively participate in the development of technology.

Technology learners should not be prepared to provide professional services to the non-indigenous contexts only, but to identify and address problems and needs in their communities to contribute towards sustainable development in those contexts. To achieve this, Technology learners should be taught to use knowledge alternatives to deal with problems facing humankind in different contexts. According to Doyle and Hill (2008), distancing teaching from the learners' community and cultural experiences has a negative effect on their learning. While we acknowledge DBE's efforts to integrate indigenous technology into the curriculum, we argue that it should also be done in practice.

Maluleke and Gumbo (2019) suggest that Technology teachers should be taught using various pedagogical strategies so that they can be exposed to different contexts to provide solutions. Pedagogies which exclude indigenous knowledge have a tendency of perpetrating a western-oriented curriculum which hinders meaningful learning in contexts such as South Africa which has many indigenous learners in their schools. Moreover, such an approach is counter the current demands that academic institutions decolonise curriculum and pedagogy (Gumbo, 2016). Gumbo (2014) adds that the integration of indigenous knowledge in South African classrooms is extremely limited and thus proposes the inclusion of indigenous technology. Teachers should adopt relevant pedagogical strategies to prove their commitment towards transformation. However, they do not seem to heed the curriculum pronouncements about indigenous technology (Gumbo, 2012). Maluleke and Gumbo (2019) argue that one of the major factors which can influence the success of learners to acquire design skills include pedagogies that facilitate learners learning in their own contexts. Failure to incorporate indigenous technology in teaching could be the reason for learners' inadequate understanding of the design concept in Technology Education. The above-stated questions can help with answers to teach Technology meaningfully to all learners.

15.2 The Methodology for Answering the Research Questions

Qualitative studies are crucial when indigenous communities are being researched due to the dominance of orality as a communication method in those communities. As a result, qualitative research helped to source the social and material circumstances, experiences, perspectives, and histories of the participants (Ritchie et al., 2013). We used a multiple case study design to collect information from the participants from three selected rural primary schools in Malamulele in Limpopo Province, to obtain a variety of perspectives about the role of indigenous pedagogies in the teaching of design skills (Moriarty, 2011). This study targeted teachers, heads of departments, and Technology Education specialists who were the main source of information as curriculum implementers. Eighteen learners also became an important source of information since they are the recipients of the curriculum in which teachers target certain knowledge and skills. To illuminate our understanding more, eighteen parents who are custodians of indigenous knowledge were also included.

Nine Technology teachers, three HoDs, and three Technology Education specialists were interviewed individually, whereas focus group interviews were conducted with six parents and six learners from each school. Semi-structured interviews were used in both the individual and focus group interviews. We asked questions, listened, expressed interest, and recorded what the participants said (Bryman, 2012; Neuman, 2011). According to Creswell (2012), personal interviews are more relevant for participants who are reluctant to share their views during a group interview. This assertion provided us with the reason to prefer one-on-one interviews with participants who might have otherwise been hesitant to express their views about indigenous knowledge in the presence of other participants. Because indigenous knowledge has suffered inferiority and low-class status which were inflicted by colonialism, indigenous people still feel that it is primitive to engage in discussions about this knowledge. Mathers et al. (1998) explain that personal interviews also benefit the researcher in the sense that he/she can clarify some questions, correct misunderstandings, offer prompts, probe responses, and follow up on innovative ideas in a way that is not possible with other methods. Semi-structured interviews also helped participants to answer our questions freely.

We first designed different interview guides for the above participant categories which were based on CRP and relevant strategies. We then arranged for the interviews with participants, which took about 45 min each. Participant observation was also used to observe all the Technology teachers about how they integrated indigenous pedagogies and strategies in teaching design activities. Gay et al. (2011) claim that by observing the classes, more objective information can be obtained, which can then be compared with the information obtained from the interviews. A checklist was used to collect data during the observations. Interviews were conducted to collect data from the participants. In consultation with the teachers, we targeted lessons which dealt with the design process irrespective of the topic which was planned for those lessons.

The data collected for this research were analysed inductively, using thematic analysis. We organised data, segmented them into manageable units, coded and synthesised them, and searched for patterns (Bogdan & Biklen, 2003). Our aim was to develop themes which would help in presenting the findings in an organised manner. We therefore read the transcribed data first and coded them to acquire new understandings of the phenomenon of interest (Strauss & Corbin, 1990). The coded data were analysed comparatively to identify the interconnectivity and relationships between categories while uncovering emergent themes; and triangulated across schools, data sources, and methods of their collection (interviews and participant observations).

15.3 Findings

The analysis of data produced four themes which were used to present the findings.

15.4 The Role of CRP in Promoting Meaningful Learning

The findings of this study showed that Technology learners sometimes do not understand the Technology lessons that do not integrate indigenous technology. This suggests that Technology teachers should consider using CRP to integrate indigenous technology which indigenous learners are familiar with. Participants were concerned about the fact that indigenous learners struggle to understand design skills. They thought that the use of pedagogies that exclude the cultural experiences of learners might contribute towards their inferior performance. A pedagogy that acknowledges the experiences of learners can boost their interest in the subject. It is in this light that CRP becomes a relevant pedagogy to include indigenous technology. According to Howard (2003), CRP is situated in a framework that recognises the rich and varied cultural wealth, knowledge, and skills that diverse learners bring to school.

The current study revealed that CRP can be used to teach learners from the perspective of their socio-cultural contexts to promote the smooth acquisition of design skills. CRP can make learners achieve greater educational outcomes when teaching reflects their own cultural experiences (Biraimah, 2016). Technology teachers can thus opt for CRP to include the customs, traditions, and beliefs of all the learners so that indigenous learners are not excluded. People are inherently cultural beings, hence integrating cultural factors in their practices should be emphasised (Moalosi et al., 2007). Technology teachers should therefore use CRP to ensure that the cultural experiences of learners are reflected when they teach design skills. Veak (2000) argues that technology cannot be separated from its cultural context. Therefore, if teachers do not teach Technology in a way that relates to the learners' cultures they might diminish their interest in the subject.

According to the participants, CRP may offer a lasting solution for many learners who struggle to comprehend design skills in Technology classes. These participants believed that this problem can be solved by teaching design skills with which learners are familiar in their socio-cultural contexts. Technology teaching should help learners to develop cooperative skills in the spirit of ubuntu which advocates solidarity, caring, and respect when solving real problems in indigenous communities. The inclusion of cultural experiences may thus inspire learners to learn.

15.5 The Use of the Inquiry Teaching Approach to Promote Indigenous Technology

This study found that inquiry, which involves the use of investigative skills, can play a crucial role in promoting the integration of indigenous technology for the acquisition of design skills. Learners' investigative skills can be developed by designing investigation activities which will encourage them to inquire from elders and indigenous experts in the communities about the design of products and how they are designed. Fraser (2006) posits that a more formal understanding of the subject matter should be built on the learners' conceptions of the world around them which includes their indigenous contexts. Therefore, participants were opined that inquiry teaching can promote the inclusion of indigenous technology in teaching design skills.

Through inquiry teaching, Technology learners can investigate problems and design for indigenous contexts instead of non-indigenous contexts only. This would mean that Technology teachers should design scenarios for the learners which are related to indigenous contexts instead of limiting scenarios to the non-indigenous contexts. For example, scenarios can be based on the building of a thatched house suited for indigenous contexts. That way, the learners' investigation activities can target skills around strengthening techniques, material choice, manufacturing, construction, etc. However, skills may not be learnt without knowledge. Therefore, in learning these skills, learners get the opportunity to learn about the properties of the used materials, tree types and their African names, processing, etc. Rutland (2009) agrees that designing explores how products were developed in the past, are currently being developed and will be developed in the future, and learners are expected to study others' designs to inform their own.

The current study found that indigenous learners are curious about indigenous technology and the skills used to make indigenous artefacts—their knowledge retention and skills can last longer if their learning is inspired by curiosity. According to Green (2010), it is much easier to recall things that fit within one's schema as they are easier to retrieve. Learners who deal with knowledge and skills that apply in their contexts on daily basis will not struggle with learning new knowledge and skills and as a result route learning will not be promoted in them. The participants indicated that the Technology learners' inquisition should be encouraged; that way they can ask questions about things that puzzle them. It is the nature of technology to puzzle people as they want to know how things work. Their curiosity can promote their understanding about different phenomena and systems.

15.6 The Use of the Discovery Teaching Approach to Promote Indigenous Technology

The findings revealed that discovery teaching can promote the integration of indigenous technology in teaching design skills. The participants indicated that in discovery teaching, learners are provided with minimal guidance when they engage indigenous knowledge which they acquired at home, to solve technological problems. They can be provided with basic knowledge only which will enable them to discover new things. According to the participants, learners can trial discoveries while dealing with any unfamiliar problems they face. They can use indigenous technology as a basis for solving new technological problems.

According to Ankiewicz and De Swardt (2001), discovery learning takes place when learners are not presented with the subject matter in its final form but are required to design and organise it themselves. An understanding of indigenous technology can help Technology learners to understand how to solve problems innovatively. According to Esjeholm (2015), learners working in Technology classrooms are supposed to be creative and to design novel artefacts. This study found that Technology learners should be provided with minimal guidance about indigenous technology so that they themselves can collect relevant data that will enable them to create innovative designs to solve identified problems. Weegar and Pacis (2012) advise that the primary role of teachers should be to motivate learners to construct their own knowledge through their individual experiences. We therefore think that knowledge construction can be nurtured among learners when it connects well with where they come from—their familiar knowledge can scaffold them into new knowledge learning.

15.7 Transforming the Current Design Process

This study established that the current design process as a method of teaching Technology is experienced differently by everyone who might be influenced by the technological activities and designs in their cultural contexts. Therefore, it needs to be reviewed to accommodate all learners in the Technology classrooms. The curriculum designers and teachers should consider approaching tasks from the points of view of distinct cultures. The participants believed that curriculum design should make provision for learners from distinct cultural backgrounds. Technology learners should be taught that cultural products can be made differently compared to the current conventional design process. The participants further indicated that the knowledge of indigenous design might stimulate creative and critical thinking in learners. According to the participants, indigenous experts do not really follow 'prescribed' steps in the design process. This implies that learners should not be coerced into following the five design steps, i.e. investigate, design, make, evaluate, and communicate as they are, but should be given the latitude to find fresh solutions creatively if Technology teachers are to develop critical, creative, and innovative thinking skills. The design principles can still be ensured even in the flexible design processes. This can lead to the constant regeneration of the design process that is attuned to teaching Technology in indigenous contexts. The participants also indicated that indigenous people learn to design through experience and only contemplate the steps they have followed designing a product. In this sense, the findings showed that indigenous people concentrate on experimentation rather than on the process. Technology learners should therefore be introduced to designing through experimentation especially during the making stage. This shows that in indigenous contexts, designing is not formally taught, but develops through practice. Technology teachers should avoid the naive use of generalist design prescriptions (De Vries, 1996). Dyson (2002) argues that indigenous people learn by trial and error. When learners learn by through trial and error, they may generate innovative ideas which can cause spontaneous thinking to thrive when they solve technological problems.

15.8 How This Might Be Used to Improve Teaching and Learning Design Skills

In this section, we discuss in detail the role of teaching the approaches and new design process in improving teaching and learning of design skills.

15.9 The Role of Inquiry Teaching Approach to Improve Teaching and Learning of Design Skills

The current study investigated the teaching methods which can be used to integrate indigenous technology in teaching design skills and help Technology teachers to understand indigenous pedagogies and teaching strategies which can enhance the acquisition of design skills. The findings revealed that the use of different teaching methods in the teaching of design skills can benefit learners, suggesting that teachers should organise their teaching activities such that they can accommodate learners from diverse backgrounds. Technology teachers should therefore be exposed to varied methods to avoid clinging to one conventional method when teaching design. Pedagogies that are removed from the local experiences of learners may negatively affect their academic performance. According to Biraimah (2016), it is anticipated that when the learners' school culture, curriculum, and their teachers' pedagogy are built on their culture, marginalised learners' achievements will improve. Singh and Reyhner (2013) confirm that when the culture of the school is too different from the home cultures of indigenous learners, they face severe identity issues and learning difficulties, hence the learning outcomes may be unachievable. Technology learners sometimes do not understand the lessons that do not integrate their indigenous worldviews, which suggests that Technology teachers should adopt the pedagogies that are friendly to indigenous technology so that learners have more chances to flourish in the teaching and learning activities. CRP is singled out as the most relevant method that can promote the integration of indigenous technology and enable learners to acquire design skills that resonate well with their environments. Learners can acquire design skills when their cultural experiences are included in learning. This will connect learning in schools with what is available in their communities.

One of the problems experienced with the use of CRP is teachers' lack of exposure to indigenous technology. This study showed that teachers struggled with the use of CRP due to their lack of relevant knowledge, which resulted in their negative attitude towards CRP and indigenous technology. They believed that indigenous technology was useless and did not advocate its use to integrate in the teaching of design skills. Thus, the teachers' beliefs go against the fact that the findings showed that an understanding of indigenous technology and CRP can help teachers to develop positive attitudes towards the inclusion of indigenous technology in their teaching. Venter (2004) suggests that teachers in South Africa should be encouraged and assisted to broaden the cultural perspectives in their practice. Technology teachers should learn to use CRP to integrate the indigenous content when teaching Technology. They should be able to select some indigenous technology which their learners know well to enhance the learners' design skills. For example, when Technology teachers teach learners about structures, they can select indigenous designs such as a sifter shown in Fig. 15.1, which is well known in some indigenous communities in South Africa. The sifter is used for sifting fine particles of ground maize and peanuts.

Fig. 15.1 Sifter

The use of CRP can allow learners to use their varied cultural wealth, knowledge, and skills to solve technological problems. The use of varied strategies related to the CRP can help to accommodate learners from diverse backgrounds.

This study also sought to establish if the inquiry teaching method may play a role in integrating indigenous technology for teaching design skills. The study found that inquiry teaching plays a pivotal role in promoting the inclusion of indigenous technology in the teaching of design skills. By learning through inquiry, Technology learners can investigate problems and ways to solve them by using indigenous skills and technology. Teachers could ask relevant questions to stimulate the learners' interest to learn and discover things on their own. The inquiry teaching method seeks to develop the learners' investigative skills. This method can enable learners to understand the products and their manipulation in their local communities.

Therefore, learners should be encouraged to investigate artefacts in their communities and gather information that can help them to make new technological products. They should be taught how to gather information about different properties of raw materials such as soil and trees which are used to make rondavels, for example. Inquiry teaching may help learners to acquire analytical skills as they identify the properties of various parts of an artefact. For example, learners may investigate the use of tie beams to reinforce a traditional bench (see Fig. 15.2). They can ask questions about why indigenous experts use a tie beam to reinforce a traditional bench. A tie beam is used in this frame structure to support the other members by pulling them together.

Technology learners should be curious about things in the technological world and not expect their teachers to spoon-feed them. They must not absorb knowledge in its current form without asking questions. For example, they should ask why certain indigenous materials and techniques are preferred to make a certain product.

Fig. 15.2 Traditional bench

Technology teachers can use inquiry method to inspire this questioning attitude in learners as to explore technology from its past to the present (Rutland, 2009).

Technology teachers should challenge learners to investigate the materials used for artefacts and to find out why those materials are preferred as it is important to understand the reason(s) for using certain materials. A material may be chosen due to its availability or strength, or because it is environmentally friendly. They can investigate the texture of an indigenous artefacts and provide the reason for preferring that texture. If it is a wooden spoon, a handle should be smooth so that it does not hurt the hands when cooking. The inquiry teaching method can also help learners to retain the knowledge and skills that they have acquired. It is usually not easy for learners to forget things that they have investigated on their own.

15.10 The Role of Discovery Teaching Method to Improve Teaching and Learning of Design Skills

The discovery teaching method may also be used for integrating indigenous technology when teaching design. Technology teachers can use a discovery teaching method to promote active learning and so allow learners to share what they know in order to understand what they do not yet know. Technology teachers can use discovery to allow learners to use their prior knowledge to solve new technological problems and determine the advantages and disadvantages of their initial ideas. A discovery teaching method may be used to acquire the idea-generating skills as learners will be given a chance to use their existing knowledge to critique its viability of making a new technological product.

It is in this light that Technology teachers can use discovery teaching if they want learners to use their prior technological knowledge to make new meaning. For

Fig. 15.3 Traditional jewellery

example, they can guide Technology learners to use their understanding of how past problems were solved to understand how they can solve a current problem innovatively as guided by the practices and activities in their indigenous environments. For example, the Tsonga indigenous people in South Africa usually use attractive colours to make jewellery such as necklaces (see Fig. 15.3). Indigenous learners may use their existing knowledge about indigenous jewelleries to make artefacts with colourful patterns which are attractive for their clients and are expression of their cultures.

The findings indicate that discovery teaching can promote the integration of indigenous technology in the teaching of design skills, and technology learners can use it to understand unfamiliar problems. The learners' indigenous technological knowledge can help them to understand that technology manifests in different forms. In indigenous communities, there are distinct types of technology such as food, pottery, baskets, and clothing technology which can be used to understand the type of technology taught in Technology classrooms. Indigenous technology can help Technology learners to find out new ways of solving problems by using indigenous techniques. The discovery method can be used to help learners to try new ways of doing things and design new products by using their prior indigenous technological knowledge.

Problems are not always similar and learners can use indigenous technology as a starting point for solving new technological problems. Technology teachers should guide learners on how to study a given scenario to detect a problem on their own without being given any clues. Technology learners should not be told what product to make; they should use their creative and critical thinking skills to find out what they can make. While Technology teachers may guide learners on how to write a design brief, learners should take responsibility for writing their own individual design briefs, which should contain brief explanations of how they intend to solve the problems they have identified. They can draw from indigenous technology to either improve an existing design or produce a new one.

15.11 The Role of Indigenous Technology-Based Design Process (ITbDP)

We advocate that the view that the current dominant design-make-evaluate method needs to be revisited to accommodate all learners. Curriculum designers should consider ways of approaching their tasks from the points of view of diverse cultures to make provision for learners from distinct cultural backgrounds. Technology learners should be taught that cultural products can be made in diverse ways, some of which have not yet been discovered. Indigenous ways used by elders to make artefacts may be used instead of relying only on western ways of designing products.

Knowledge of indigenous ways of designing might stimulate creative and critical thinking in learners. This study revealed that indigenous experts do not really follow 'prescribed' steps in the design process. The initiates are not coerced to follow steps when they design products. Novices are just allowed to observe the experts when designing new products. The observers can practise designing new products according to their own understanding. Learners should not only be instructed to follow five design steps, i.e. investigate, design, make, evaluate, and communicate, but should be given the latitude to find fresh solutions by using their own steps. This can lead to the constant regeneration of the design process that is suitable to teaching Technology in indigenous contexts.

Indigenous people usually learn to design through experience and only contemplate the steps they had followed designing a product. They practice making products and from practice they acquire skills and learn to design by experimentation. The findings showed that indigenous people concentrate on experimentation rather than on the process. This shows that in indigenous contexts, designing is not 'formally' taught, but develops more through practice. The findings also showed that there are alternate ways to promote the acquisition of design skills, such as the use of CRPs. Thus, indigenous design ways should be acknowledged as they can facilitate the acquisition of design skills.

The design process, which includes a range of design skills was explained in line with the CAPS prescription (investigate, design, make, evaluate, and communicate). It was shown to be both the dominant content and method in the teaching of Technology. This study highlighted a different view of design that is inspired by how designers in indigenous contexts approach design and make artefacts. The design process that flows from this context hinges on the key aspects of analysis, culture, materials, apprenticeship, make, and evaluate which are intertwined and centred more on the elders' and local designers' guiding roles. These aspects should therefore be understood in a holistic and interactive manner. Hence, the indigenous conceptualisation of design suggests an indigenous technology-informed design process, which the authors decided to call an indigenous technology-based design process (ITbDP) (see Fig. 15.4). The ITbDP whose key aspects are culture, analysis, materials, apprenticeship, make, and evaluation, can be used in the Technology classrooms to integrate indigenous technology in teaching design skills.

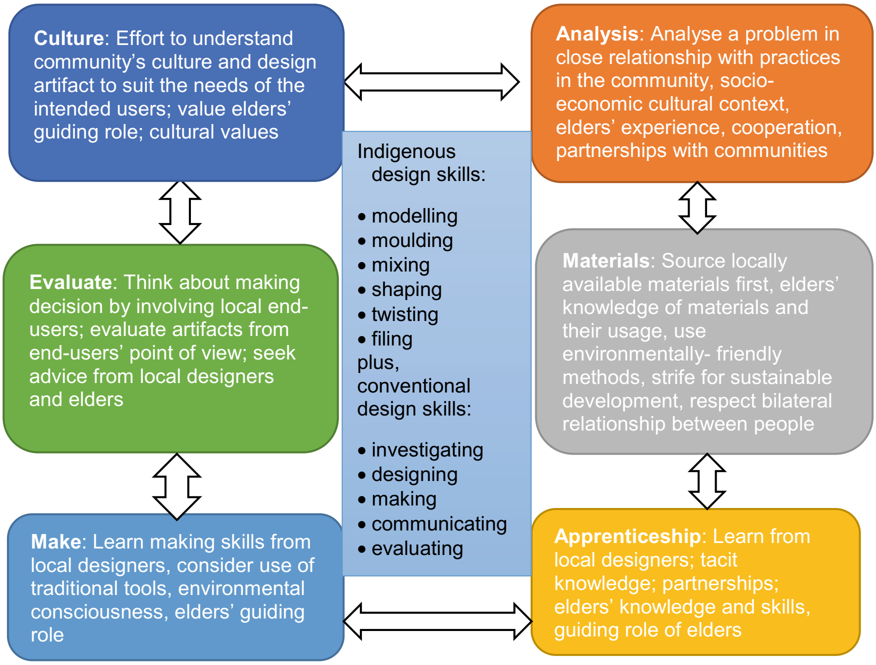

Fig. 15.4 Indigenous technology-based design process (ITbDP)

15.12 Conclusion

The main research aim of this study was to explore the strategies related to CRP to facilitate the integration of indigenous technology in teaching design skills in Technology Education classes. This aim has been achieved by focussing on how indigenous pedagogies can be instrumental in the teaching and acquisition of design skills. The purpose of this section is to conclude our thoughts about this. Design skills are required in modern societies to solve technological problems which emerge from time to time. Technology teachers should be able to use indigenous pedagogies such as CRP as it promotes the integration of indigenous technology in teaching. This chapter has shown how this can be achieved with respect to teaching design skills. The use of indigenous pedagogies can motivate learners to use different technological knowledge systems to solve technological problems instead of restricting them to one technological knowledge system only.

Therefore, this study suggests that Technology teachers should also use indigenous technologies to inculcate design skills taught in their classrooms. They should avoid relying exclusively on western content and pedagogies. Instead, they should attempt different strategies or methods such as inquiry and discovery to ensure the integration of indigenous technology in their teaching activities. This may help to initiate learners into design skills which are used by indigenous experts and engineers to make new products. The experiences of people in different geographical areas, including indigenous people, should be considered in the teaching of Technology. Technology is the application of existing knowledge and resources to solve real problems. Hence, Technology learners should be taught to use different knowledge systems including their local knowledge to solve technological problems.

We suggest that Technology teachers should learn to use the ITbDP in the teaching of design skills for accommodating all learners in their classrooms. The use of ITbDP can help Technology teachers to accommodate the real experiences of learners which are usually excluded. We suggest that the educational officials who are responsible for teacher training take advantage of ITbDP to ensure that indigenous technology is not just a policy requirement but is implemented also.

Furthermore, ITbDP can encourage unconventional approaches to the design process instead of perpetuating conventional approaches. The unconventional approaches of design can help learners to design solutions for their local contexts as a priority and contribute towards the existing technology in such contexts. Action research may be a useful approach to refining ITbDP. In this sense, learners may be guided through ITbDP as they critically reflect on their proposed designs in relation to their contexts. Technology teachers can conduct action research to establish the strength(s) and weakness(es) of ITbDP in their respective contexts. They may also use action research to establish the relevance of an indigenous pedagogical method in teaching design skills. To learn more about the relevance of indigenous pedagogies and ITbDP, Technology teachers may involve the technological knowledge holders, especially elders in their communities, to conceptualise designs with them.

References

Ankiewicz, P. J., & De Swardt, A. E. (2001). *Technology education: Principles, methods and techniques of Technology Education II*. University of Johannesburg.

Biraimah, L. B. (2016). Moving beyond a deconstructive past to a decolonised and inclusive future: The role of ubuntu-style education in providing culturally relevant pedagogy for Namibia. *Internationally Review of Education, 62*(1), 45–62.

Bogdan, R. C., & Biklen, S. K. (2003). *Qualitative research for education: An introduction to theories and methods.* Pearson.

Bryman, A. (2012). *Social research methods.* Oxford University Press.

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research.* Pearson.

De Vries, M. J. (1996). Technology education: Beyond the technology is applied science paradigm. *Journal of Technology Education, 8*(1), 7–15.

Department of Basic Education. (2011). Curriculum and assessment policy statement Grades 7–9: Technology. Government Printers.

Doyle, L., & Hill, R. (2008). Our children, our future: Achieving improved primary and secondary education outcomes for indigenous students: An overview of investment opportunities and approaches. AMP Foundation. Retrieved May 1, 2014, from http://www.amp.au/ampfoundation.

Dyson, L. E. (2002). Designing for a culturally affirming indigenous computer literacy course. Paper presented at the ASCILITE annual conference of Australasian society for computers in learning in tertiary education, Auckland, New Zealand.

Esjeholm, B. T. (2015). Design knowledge interplayed with student creativity in D&T (Design & Technology) projects. *International Journal of Technology and Design Education, 25*, 227–243.
Fraser, J. D. C. (2006). Mediation of learning. In M. M. Nieman, & R. B. Monyai (Eds.), *The educator as mediator of learning*. Van Schaik.
Gay, R. L., Mills, G. E., & Airasian, P. W. (2011). *Educational research: Competencies for analysis and applications*. Pearson.
Green, B. A. (2010). Understand schema, understand difference. *Journal of Instructional Psychology, 37*(2), 133–145.
Gumbo, M. T. (2012). Claiming indigeneity through the school curriculum, with specific reference to Technology Education. *African Education Review, 9*(3), 434–451.
Gumbo, M. T. (2014). An action research pilot study on the integration of indigenous technology in Technology Education. *Mediterranean Journal of Social Sciences, 5*(10), 386–392.
Gumbo, M. T. (2015). Indigenous technology in Technology Education curricula and teaching. In P. J. Williams, A. Jones, & C. Bunting (Eds.), *Contemporary issues in Technology Education: The future of Technology Education*. Springer.
Gumbo, M. (2016). A model for indigenizing the university curriculum: A quest for educational relevance. In V. Msila, & M. T. Gumbo (Eds.), *Africanising the curriculum: Indigenous perspectives and theories*. Sun Press.
Howard, T. C. (2003). Culturally relevant pedagogy: Ingredients for critical teacher reflection. *Theory into Practice, 42*(3), 195–202.
Maluleke, R., & Gumbo, M. T. (2019). A cultural responsive pedagogy for teaching design skills in Technology: An indigenous perspective. Paper presented at 27th annual conference of the South African association for research in mathematics, science and technology education (SAARMSTE), Durban, South Africa.
Mathers, N., Fox, N., & Hunn, A. (1998). Using interviews in a research project. Trent Focus Group.
Moalosi, R., Popovic, V., & Hickling-Hudson, A. (2007). Product analysis based on Botswana's postcolonial socio-cultural perspective. *International Journal of Design, 1*(2), 35–43.
Moriarty, J. (2011). *Qualitative methods overview*. School for Social Care Research.
Neuman, W. L. (2011). *Social research methods: Qualitative and quantitative approaches*. Pearson.
Ritchie, J., Lewis, J., Nicholls, C. M., & Ormston, R. (2013). *Qualitative research practice: A guide for social science students and researchers*. Sage.
Rutland, M. (2009). Art and design and design and technology: Is there creativity in the designing? *Design and Technology Education: An International Journal, 14*(1), 56–67.
Singh, N., & Reyhner, J. (2013). Indigenous knowledge and pedagogy for indigenous children. In J. Reyhner (Ed.), *Honoring our children: Culturally appropriate approaches for teaching indigenous students*. Northern Arizona University.
Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Sage.
Veak, T. (2000). Whose technology? Whose modernity? Questioning Feenberg's questioning technology. *Science, Technology & Human Values, 25*(2), 226–237.
Venter, E. (2004). The nation of ubuntu and communalism in African educational discourse. *Studies in Philosophy and Education, 23*, 149–160.
Weegar, M. A., & Pacis, D. (2012). A comparison of two theories of learning: Behaviorism and construction of applied to face-to-face and online learning. Paper presented at the E-leader, Manila, Philippines.

Richard Maluleke obtained his Doctor of Education degree in 2019 from the University of South Africa. His other qualifications are MEd (UNISA), BEd (Hons) (University of Johannesburg), FDE (University of Johannesburg) and SPTD (Soweto College of Education). He began his teaching career in 1999 at St Mary's College where he taught Mathematics and Technology subjects. He also taught the same subjects in Sedimosang Primary School from 2002 to 2004. He is currently teaching at Nkone Maruping Primary School. He has extensive experience in teaching

Mathematics and Technology. He is interested in indigenous technology. He is currently being mentored by Professor M.T. Gumbo with whom he has co-authored and presented three international conference papers. He is a member of Southern African Association for Research in Mathematics, Science and Technology.

Mishack T. Gumbo is a Full Professor attached to Department of Science and Technology Education at UNISA. He holds a Ph.D. in Technology Education [indigenous technology and curriculum] (Vista University), MEd [Technology Education] (University of Johannesburg), MPhil [Applied Theology] (University of Pretoria), MEd [Open Distance Learning] (University of South Africa), BEd Hons (University of South Africa), BA (Vista University), UED (Vista University) and ORT-International Certificate in Technology Education (ORT-Step Institute). He specialises in Technology teachers' professional development and the integration of indigenous knowledge in the curriculum and teaching. He worked at Vista University and University of Pretoria. Prof MT Gumbo has successfully supervised seventeen doctoral students and eight master's students. He has published extensively, presented conference papers, and delivered keynote addresses. He heads a research and community engagement project on the professional development of MST teachers.

Chapter 16
Implementing Digital Tablet Activities in Swedish Preschool Education

Anna Otterborn and Konrad Schönborn

Abstract Preschool curriculum policies around the world emphasize the role of digital tools in educational practice. At the same time, the availability of tools such as tablets has increased significantly in the last decade. Although preschools have worked with these tools during the last years, little is known about what actual activities teachers implement and perform in practice and how digital tablets can be effectively integrated. In contributing to filling this gap, we used online surveys to probe approximately 500 teachers' use of digital tablets in their practice. Results showed that teachers believe that tablets increase both collaboration and participation. In connection with the subject of technology, many creative ideas and solutions evolved. Computer programming activities also emerged saliently, which the teachers saw as a means to foster generic skills and subject knowledge. The findings point to digital tablets being associated with preschool teachers' implementation of meaningful, engaging, self-generated, and rich activities. In helping to integrate emerging digital tools in educational practice, teachers are encouraged to consult online forums, web resources, available online courses, and articles. Teachers are also advised to allocate the necessary time required to plan and implement the work.

Keywords Preschool education · Digital tablets · iPads · STEM-related subjects

A. Otterborn (✉)
Science and Technology, Örebro University, Örebro, Sweden
e-mail: anna.otterborn@oru.se

K. Schönborn
Media and Information Technology, Linköping University, Linköping, Sweden

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_16

16.1 The Questions that Were Asked and Why They Are Important

The purpose of this chapter is to describe preschool teachers' use of digital tablets, in general, and with respect to teaching the subject of technology as well as in relation to programming activities. The contribution also considers how teachers can realize this work in practice. The following questions are raised:

How do teachers use digital tablets in their preschool educational practice? (*What is happening out there?*)

How do teachers use digital tablets in educational work with the subject of technology? (*Do teachers successfully implement digital tablets in their work with the technology subject?*)

How do teachers implement programming in their practice? (*What programming activities occur in preschool?*).

The impact of digital development on society has been immense and parallels a significant increase in human engagement with digital technologies, such as digital mailboxes and hand-held interactive communication devices. Such widespread use has impacted preschool teachers' pedagogical work. Indeed, children must acquire new knowledge and skills for digital participation and inclusion. In this regard, digital tools such as tablets provide new opportunities for education and have also led to various changes in curriculum policy around the globe. Thus, children's development of digital skills is formulated as *imperative* in many new preschool curricula, as is the case in Sweden, where programming is also included as part of the technology subject in the compulsory school curriculum (Cederqvist, 2020).

Based on regulatory documents, teachers are expected to work with digital tools as a natural part of their pedagogical practice. In line with this expectation, results show that many teachers have made significant efforts to integrate digital technologies into their teaching. The use of digital tablets often takes place in, among other subjects, the teaching of different STEM-related domains in technical areas such as programming, invention, construction, creation, problem-solving, and design (see Table 16.1 later). The "T" in "STEM" often represents "technology;" however, the interpretation of what this "T" actually signifies, in essence, is a subject of scholarly debate (Fridberg & Redfors, 2021). For the purpose of this chapter, the T includes design and technology subject content, aside from whether or not it integrates digital technological intervention in its pedagogy.

It is vital that educators adopt a conscious educational strategy to exploit the benefits of digital tools such as digital tablets, and not merely assume that replacing the analogue on its own shall suffice (Bers, 2018; Falloon, 2013; Otterborn et al., 2019; Popat & Starkey, 2019). In addition, literature (Bers, 2018) shows that the perceived need for children to gain digital competence is increasing. Therefore, preschool offers a fundamental arena for creating digital participation for all, where children are also active creators of the activities (Kress, 2003).

There is little doubt that digital tools will continue to be important in society and thus in the preschool context at large. However, research on the educational

Table 16.1 Examples of technology content areas and related tablet activities with corresponding apps used at the preschool level in Sweden (Adapted from Otterborn et al., 2019)

Technology content area	Examples of activities described in verbatim survey responses	Example of app or programme used
Programming	Using digital tablet apps in the programming of robotic movements on the floor Building robots with Robot Lab and then using the programming app Light Bot. As a prize, we play dress up and walk on large self-built [obstacle] courses	Blue-bot Robot Lab, Light Bot
Invention	Children build their own inventions using applications The Brio World app is used frequently in connection with railway construction "in reality." The children then build both a digital and analogue rail	Pettson's Inventions Brio World
Construction and creation	Looking for images and movies of construction to inspire children's building of their own [artefacts] and, drawing them on paper [Obtaining] inspiration by the construction and building from other preschools, for example, we have searched for car tracks and then built our own [from our] own ideas	YouTube You Tube
Creativity and problem-solving	Reflecting [upon] as well as creating movies together with the children where they foster their imagination and creativity Problem-solving	iMovie Inventioneers
Design (Technology enhanced design investigations) Design	Using a WiFi microscope to explore objects. The magnified images allow children to visualize objects at higher levels of detail Children create books and [narrative] series with their own pictures	WiFi microscope together with Ucam Strip design

effects of digital tools such as tablets is still emerging (Nilsen, 2018). Some studies point to relationships between poor reading comprehension and the use of digital tools (Rosén, 2011). At the same time, a study by Neumann and Neumann (2014) provides evidence that children's verbal literacy skills improve when using digital tablets. There is also a need for more research on technology as a subject in its own right at preschool (Elvstrand et al., 2018). In this regard, few studies have identified tablets as a means to teach technology content matter (for example, children digitally photograph their newly built constructions and then reflect on this activity together with others). This chapter intends to contribute to this area, not only by informing the community about current tablet-related activities deployed by preschool educators but also to advise how practical work might be carried out in a preschool context. Although the described research was carried out in a Swedish context, the general focus on tablet technology as an educational tool makes it potentially relevant for other international settings.

16.2 How the Questions Were Answered

With the purpose to discover more about how teachers actually work with digital tablets in preschool as part of teaching STEM-related domains, this study used online surveys as a method to access a large pool of educators' views across Sweden. One advantage of this method is that both quantitative and qualitative data can be generated within a relatively short data-collection period (Robson & McCartan, 2016). As a theoretical perspective, Seymour Papert's constructionism, which has its roots in constructivism (Ackermann, 2001), was used to consider the role of programming in preschool. For example, ascertaining Papert's (e.g., 1980) emphasis on the child's active role and the importance of the collaborative teacher in creating the conditions for this work. The analyzed data comprised 526 survey activations and included both open and closed item responses.

Survey questions were designed to investigate how teachers use digital tablets as educational tools in general but also with an added focus on STEM-related subjects. The objective was also to determine how programming activities (such as programming a robot to navigate a path) are implemented in preschool and to gain teachers' views in this regard. The survey also retrieved demographic dimensions including age, gender, level of education, and geographical location of respective preschools. In addition, educators were asked to state which programs and "apps" they used in their work and why they used them. Questions on the number of available tablets and what digital competence the educators perceived themselves to have were also posed.

Survey respondents were also asked to provide their views on the advantages and disadvantages of using digital tablets in preschool activities. We also sought their responses about how they used these artefacts in connection with the teaching of technology and science. Additionally, responses to how often these activities occur, as well as what related activities took place, were also gathered. Furthermore, questions were posed around any recommendations that teachers wished to make about the use of tablets in preschool education. In connection to programming, questions were asked about which areas benefit from programming in preschool activities, how often teachers programmed with the children, and who took the initiative to start programming at preschool (e.g., teachers themselves or preschool managers).

Questions were also presented about whether teachers included programming content without digital tablets and what apps teachers use when programming with tablets.

16.3 What Was Found Out?

This section is structured by responding to the posed chapter questions concerning preschool teachers' use of tablets in their general practice, as part of teaching the technology subject, and in computer programming activities.

16.3.1 How Do Teachers Use Digital Tablets in Their Preschool Educational Practice?

Our studies found that teachers have a genuine desire to develop pedagogical initiatives with digital tablets, and many creative activities and interventions emerged. These include creating books with children's own pictures or searching for (scientific) facts. Additionally, teachers were shown to be "one step ahead" of respective preschool principals' decisions by often displaying their own self-initiation of different activities (such as programming) in implementing digital tablets while also acknowledging that they are certainly not experts. Results also show that respondents think that tablets are flexible and easy to handle. The ability to rapidly search for facts was also something that teachers appreciated. Moreover, teachers believe that children's levels of collaboration and participation increase when working with tablets. Also, it was felt that interacting with tablets facilitates critical thinking and social skills.

As presented in Fig. 16.1, the survey results revealed eight categories of implemented pedagogical activities by teachers. The categories included developing the use of language in different forms, hands-on and active exploration of technology and science content (including programming activities), engaging and developing mathematics concepts and skills, and thematic approaches involving focussing on a particular content area or project. In addition, social skills such as engendering different types of cooperation and democratic values were associated with tablet activities. Furthermore, concerning generic skills, we observed that the most prevalent activity was teachers' development of activities involving discussing and reflecting on documentation materials (such as pictures) together with children. Also, using apps for fact searching as well as developing children's critical thinking abilities with the help of digital tablets was a further identified activity.

Teachers' responses to the two online surveys indicate that they are well prepared for the increased demands of digitalization that the new Swedish preschool curriculum puts forth. Nevertheless, teachers point to the need for specific skill development and more explicit curriculum directives. Many teachers in preschool lack the

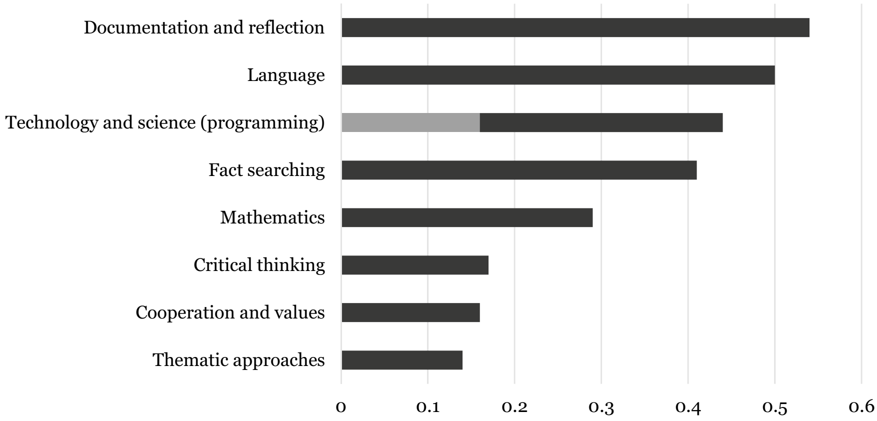

Fig. 16.1 Main categories of digital tablet activities implemented by Swedish preschool educators in their practice, together with response incidence (%) obtained from the survey (n = 288). As part of the technology and science category, 16% (grey) of responses specifically mentioned programming activities

knowledge (i.e., what can be done with digital tablets to support my pedagogical work?) and feel insecure (i.e., how do I perform it?) with respect to digitalization (cf. Marklund, 2020). Results also revealed that digital tablets were the most represented form of interactive digital device used in the preschool classroom. Overall, teachers make use of tablets in connection with technology, science, language, mathematics, documentation, and reflection, cooperation and values, critical thinking, thematic approaches, and fact searching (see Fig. 16.1). As part of working with tablets, teachers use various educational apps, activities, artefacts, and internet-based resources.

As previously mentioned, the teachers in this research sought clearer and more informative guidelines (for how to perform the work) in the curriculum regarding the implementation of digital tablets. They also expressed the need for skill development and for closer collaboration between municipal management, principals, and teachers in preschools. They raised the importance of the children's perspectives (taking their interests and needs into account) and more opportunities for children to influence learning in this area. However, at the same time, it was deemed important to reach a trade-off when it comes to how long and when children should be allowed to work with tablets and what applications should be permitted. Furthermore, teachers should be ensured with and offered time resources to effectively plan for the implementation of digital activities. Equipment adapted for preschool needs (such as sufficient numbers of digital tablets) were also expressed recommendations regarding the development of educational activities with digital tablets.

16.3.2 How Do Teachers Use Digital Tablets in Educational Work with the Subject of Technology?

Literature suggests that there is insecurity from many teachers in terms of approaches to teaching technology as a subject (Stables, 1997; Sundqvist, 2019). The same applies when it comes to implementing emerging digital technologies as part of educational practice. Teaching quality also differs considerably between preschools, as demonstrated in a survey conducted by Skolinspektionen (2017). Historically, the technology subject has not had the same prominent role as other subjects such as science in the Swedish preschool curriculum, although an increased emphasis on both technology and science can be noted in the two most recent curriculum revisions. Teachers are now more directed to provide children with learning opportunities to develop their knowledge in technology. Also, to promote activities for children to explore how simple technologies function, as well as develop their ability to build, create, and construct (Skolverket, 2018a). Within preschool education, it is traditional to work across subjects, where technology and science are often interconnected (Elvstrand et al., 2018). Consequently, teachers do not always have clarity concerning what content should be delivered and how different subjects, such as technology, should or should not contribute to various activities.

The results of this research provide multiple examples of developed activities in the subject of technology. Teachers also demonstrated that the use of tablets takes place in different technical content areas (see Table 16.1). Furthermore, one advantage of the digital tablet is that while children document a phenomenon as part of a technology activity, the tablet provides a platform for active reflection, which may promote the child's focus on the task at hand. These results also suggest that in combination with cognitive support, such as increasing the children's perspectives, teachers encourage children to conduct various technology activities with digital tablets, including programming, which could support logical thinking and problem-solving abilities (Bers, 2018). Also, using digital applications concerned with construction, creation, and design activities could stimulate inventive, innovative, and entrepreneurial skills and feed children's natural curiosity. Results indicate that digital tablets and associated apps are being used to support teachers and children in their technology teaching.

The examples that emerged show that teachers use at least ten programs and apps in association with their implementation of technology content tablet activities (Table 16.1). The activities also reflect the content of the curriculum.

16.3.3 How Do Teachers Implement Programming in Their Practice?

The survey responses showed that teachers placed a strong emphasis on integrating programming activities in combination with digital tablets. Two-thirds of the respondents stated that they programme together with the children. Almost half of the educators noted that the programming work stemmed from their own initiative. Here, too, the educators seem to be initiators. Various apps (such as Blue-Bot, Bee-Bot, and Lightbot Jr) and accessories (such as robots) are used together with digital tablets in connection with programming activities. On this score, there is increasing access to tangible, concrete educational technology adapted for preschool children (Bers et al., 2013; Otterborn et al., 2020).

Educators implement both unplugged programming (without digital tablets but through bodily activities or using different objects and apparatus) and digital programming (exclusively with digital devices or in combination with physical objects). Teachers also stated that they combine unplugged and digital programming, often commencing with unplugged programming so as to concretize the content in focus (cf. Faber et al., 2017; Gomes et al., 2018; Mannila, 2017). Here, it is common for children or teachers to physically adopt the role of a robot with one or more children instructing and navigating the "robot." Also, some classes perform yoga and gymnastics with the help of verbal instructions or/and instructions on paper in the form of symbols or photographs. Other activities that teachers highlighted during programming were sorting objects such as beads to distinguish between different properties, create patterns, and follow sequences.

As for digital programming, using robots such as Blue-Bot is common. One can programme the Blue-Bot independently using buttons on top of the robot or control the robot from a digital tablet, in combination with an installed Blue-Bot app. A third alternative is to control the Blue-Bot with block programming in the form of a standalone unit with tactile trays, such as through the Blue-Bot Tactile reader. Digital programming is also often extended in the construction of other objects in what is referred to as physically extended programming. Here, various materials can be used, for instance, to create paths and obstacles for the robots. To represent different characters and animals, robots such as Blue-Bots can also be "dressed up" (e.g., as a ladybug) and programmed to reach different goals. In the latter, the robot must navigate between various obstacles to reach a defined goal. Other examples of using robots include attaching a pencil to a Blue-Bot so that children can programme the robot to draw geometric shapes. Another activity involves the teacher reading a story to the children, followed by placing images from the story on the floor under a transparent mat divided into squares. The children then recount the story while programming Blue-Bot.

Programming activities are also often integrated into project work, which makes programming more personally meaningful for the children (Papert, 1980). In this work, several curriculum objectives are also included from multiple subjects, such as science, technology, mathematics, and language (also see Heikkilä & Mannila, 2018). In this regard, we observe that many aspects of traditional teaching are being recontextualized in terms of programming activities. Teachers also often stated the opinion that programming activities favour children's development of computational thinking and "twenty-first-century skills" (e.g., Bers et al., 2014; Mannila, 2017). Moreover, the results showed that the teachers use a supportive approach to promote the work, leading the child to perform a task that they would not have otherwise managed without assistance (cf. Benton et al., 2018; Lye & Koh, 2014; Neumann & Neumann, 2014).

Overall, teachers seem to view programming activities as an eventual new lingua franca, used for the child to learn various generic skills (Otterborn et al., 2020). As shown in Table 16.2, three overall clusters of learning objectives emerged from the programming work communicated by teachers' survey responses (Adapted from Otterborn et al., 2020).

The following described project work from a preschool environment serves as an example of activities in the form of a vignette that draws on all three clusters in Table 16.2. In opening up for potential dialogue between all participants, preschool teachers divide children into smaller groups during the day (see Table 16.2, cluster

Table 16.2 Three overall clusters of learning goals connected to preschool programming activities in Sweden

Overall cluster	Learning goals
1. Overarching learning outcomes concerning a digital society	• Understand the digital world • Understand that a human being controls the computer/robot • Obtain a concrete understanding of what happens in programming
2. Programming-related skills and learning goals	• Generate an understanding of symbols and how they can be used (in the case of unplugged programming, this relates to symbols indicating how to move the body, or to use arrows or symbolic representations in certain positions) • Develop, provide, interpret, and perform instructions that include following a specific order/sequence or perform stepwise procedures • Break down a task into smaller task components • Debug and attempt the task/procedure again when required
3. General skills and abilities	• Trust in one's own ability • Develop new ideas/inventions, create, and design • Understand that there are different ways to solve a problem and reach a solution • Develop collaborative, motor, and social skills

3). To demonstrate this, we present the following vignette of how a one-week project about the local environment can be set up and implemented in the activities that children and teachers engage in.

One teacher and seven children (four to six years old) gather in one of the preschool rooms. Conversations are held about the day's upcoming walk through the city. Among other aspects, participants discuss a map (with different landmarks) that has been projected (using a digital tablet and a projector) on the wall. The children point directly at the projector cloth (on the wall) and follow the different roads with their fingers to see how to walk to get to the different landmarks and how to get back "home" to the preschool (see Table 16.2, cluster 2). For further clarification, the Google Earth app is also used in combination. An intense discussion with many questions arises. Also, joint decisions are made about where to go (see Table 16.2, cluster 3).

When the teacher and the children return to the preschool from the city walk, and where the children have also photographed different landmarks with the help of digital tablets (see Table 16.2, cluster 3), they all reconvene in a room. A tablet is connected to a projector; they view and reflect on the pictures taken. Paper sheets are also laid out on the floor, and the children paint a map of the parts of the city that they have visited previously in the week. The map they looked at the day before is again projected onto the wall. A Blue-Bot robot is retrieved so that the children can measure it and ensure that it has room to "walk" on the roads that they construct (see Table 16.2, cluster 2). While the paint dries, the children use other materials to recreate some of the buildings that they saw and visited during the trip. The children are eager and try different strategies to perform the activities (see Table 16.2, cluster 3). At the same time, the teacher encourages them and provides support while still allowing the children to test and make mistakes and receive help in understanding that making errors is a natural part of learning (see Table 16.2, cluster 2). The teacher puts a lot of effort into making all the children feel included in the joint work. Various complementary activities are implemented for an increased understanding. For example, the teacher reads the story of the three pigs (on a digital tablet), where the hungry wolf blows down all but one (well-built brick) house.

Some of the buildings are now in place, and it is time to programme the Blue-Bot to navigate to different landmarks. To make the task more concrete, the teacher chooses to start the activity by dressing up as a robot and allowing the children to "program" her (see Table 16.2, cluster 1). The children cooperate and help each other in this work, much enjoyable laughter arises, and the atmosphere becomes light-hearted, which also formed part of the teacher's original intentions. The reserved children that tend to shy away from speaking have the opportunity to lay out different symbols such as arrows to "program" the teacher (see Table 16.2, cluster 2). Then, the programming of the Blue-Bot robot begins. Several robots are picked up and handled so that the children have a focussed opportunity to physically interact with a respective Blue-Bot and deduce its controls (see Table 16.2, cluster 1). The teacher lets the work take its time, and it is repeated in several iterations. When such programming activities begin to become a natural part of the preschool's everyday life, and the children develop more confidence, the teacher challenges the children more, and the tasks become increasingly difficult (see table 16.2, cluster 3). Simultaneously, as the work with the model of the local environment progresses, the children and the teacher discuss what is programmed or not. The model is not limited to buildings—flowers, trees, and animals are also aspects that are included.

During one of the recurring walks in the local environment, one of the boys discovers a beautiful flower that he photographs. This leads to the teacher and the children programming Blue-Bot to use a felt pen attached to Blue-Bot to generate a flower by drawing six circles, a circle in the middle and the remainder on the periphery. Small paper flowers are also crafted to fit into the model of the local environment. The subsequent weeks that follow are devoted to talking about different plants. The project is thus also influenced by what the children show interest in, and the learning progression can alter direction from one week to another, while the local environment remains the focus (see Table 16.2, cluster 3).

16.4 How This Might Be Used to Improve Teaching and Learning

In this section, we describe components in educational settings that might help provide awareness and support in preschool teachers' work with digital tools such as tablets. We also provide some potential practical avenues for supporting such work.

16.4.1 Digital Tablets as a Means for Supporting Preschool Education

Digital tablets were very well received by preschool teachers when they became available on the market (Nilsen, 2018). Our study indicates that educators see numerous advantages with tablets, such as their role in supporting collaboration and participation. In addition, study results show that many inventive and creative ideas develop when teaching with these tools, where tablets complement analogue curriculum work and allow children to engage in various creative activities, such as attaching a pencil to a robot and programming it to draw (Otterborn et al., 2019, 2020). Such examples of specific tasks and teaching opportunities could in themselves serve as motivation and guidance for teachers who are implementing this work in their own preschools. Digital tablets can support authentic learning, and our results particularly indicate that the use of tablets facilitates teachers' work with various STEM subjects (Couse & Chen, 2010; Hallström & Schönborn, 2019; Otterborn et al., 2019, 2020). These subjects also integrate aspects of programming, invention, construction, creation, problem-solving, and design, as well as the demonstration of technology concepts and processes (Couse & Chen, 2010; Otterborn et al., 2019, 2020). Other subject areas (such as language literacy) that connect to the curriculum can also be harnessed with tablet activities, e.g., by creating stories with the help of different apps (Neumann & Neumann, 2014; Otterborn et al., 2019, 2020).

While many teachers have started in earnest to meet the demands of the new curriculum with fruitful results (many), educators still feel unsure in how to effectively address the expectations of the curriculum. Consequently, there is a call from teachers for clearer directives and more training, but the current Swedish preschool curriculum does not seem to offer the lucid guidelines that teachers seek. Nevertheless, the wording in the curriculum document makes it imperative that teachers integrate pedagogical activities to develop children's digital skills and understanding.

16.4.2 Multiple Factors Influence the Integration of Digital Tools in Preschool Education

This study and earlier investigations highlight the importance of teacher competence both when it comes to the use of educational technology such as digital tablets (Bers, 2018; Marklund, 2019; Nilsen, 2018) as well as the teaching of the subjects of technology and science (Elvstrand et al., 2018; Stables, 1997; Sundqvist, 2019). To enhance children's development, teachers must have a conscious educational strategy in mind (Bers, 2018; Falloon, 2013; Kjällander & Riddersporre, 2019; Nilsen, 2018; Otterborn et al., 2019, 2020). Therefore, it is of utmost importance that educators are aware of the necessity to be present, offer support, and challenge the children during this work (Flewitt et al., 2015; Nilsen, 2018; Palmér, 2015). Petersen (2015) stresses that children's agency is enhanced when working with teachers. At the same time, children's independent activities should be encouraged based on their own perspectives and experiences (Papert, 1980; Petersen, 2015). It is of utmost importance that the students are provided with support from the teachers even during self-sustaining learning activities. Here, teachers also need to pay attention to the fact that although many children are often adept at managing digital tablets alone, it is essential for teachers not to overestimate children's competence. Educators must be aware of students' different levels of knowledge in this area, or else there is a danger for a widening digital divide (Mertala, 2019; Nilsen, 2018; Selwyn et al., 2020; Walldén Hillström, 2014). In addition, there are significant differences between children's use of digital tools based on various factors that include software used and the nature of support offered by guardians and caregivers (Common Sense Media & Rideout, 2011).

Considering the quality of the applications used is also of high importance (Palmér, 2015). Many available apps are perhaps not directly suitable for educational practice (Falloon, 2013; Palmér, 2015; Kjällander & Riddersporre, 2019; Nilsen, 2018). To choose pedagogically useful apps, the teacher must have expertise in this area, which might be provided by internet forums, collegial learning, and supplementary training. Indeed, research indicates that the apps selected affect both children's and teachers' actions, such as children's agency and active participation (Palmér, 2015).

For example, many apps contain unnecessary or extraneous text, which makes it difficult for children to act on their own (Falloon, 2014). There are both "closed" (focus on receiving "correct" or "incorrect" responses) and "open-ended" (opportunities for problem-solving and custom creation) apps. Although teachers often prefer open-ended apps (Kjällander & Riddersporre, 2019; Otterborn et al., 2019, 2020) such as Imovie, Strip Design, and Inventioneers (see Table 16.1), even closed apps can be an asset, such as memory apps (Palmér, 2015). It is also crucial to know when to use various apps and respective digital tools (see Kjällander and Riddersporre 2019). This requires being constantly aware that digital tablets should complement and enhance other activities and not replace them.

Overall, our research shows that many educators have high expectations of digital tablets as a medium for supporting teaching (Otterborn et al., 2019, 2020). To exploit the full potential of tablets, we argue that teachers' careful preparation is critical in integrating educational digital activities. Teachers must integrate these activities actively in practice to complement and enhance otherwise traditional approaches. In addition, it is essential that the work is given the necessary time, both when it comes to planning and implementing classroom activities.

16.4.3 Practical Advice for Preschool Educators' Use of Tablets During Teaching

In the final component of this chapter, we reflect on our findings in the form of providing some practical avenues for exploiting the potential benefits of tablets in the classroom.

Promoting digital competence and work strategies:

- While waiting for competence development (when needed) not yet offered by managers/principals, teachers can already commence their digitalization work by expanding their knowledge gradually (one way to start can be to photograph and film). Support in this mission can be obtained from sources such as online forums, home pages, online courses, books, and articles. One good example of programming can be found at the following link: www.youtube.com/watch?v=0_jBxUlh0zY&t=9s (Skolverket, 2018b).
- Use a deliberate pedagogical strategy in the work. Be present and give the children support.

Preventing a "digital divide":

- Children's knowledge differs even when it comes to digital tools such as tablets. Adapt your activities with this in mind.

Locating and using suitable apps:

- Place an effort in choosing appropriate applications. Homepages such as www.skolappar.nu (in Sweden) and www.naeyc.org (internationally) are helpful.
- Choose one app at a time and get to know the application before the classroom introduction.

Considering questions around purpose, interests, needs, and goals:

- Systematic preparation and planning are crucial. Also, ask yourself the following questions: Why will do we do this digital activity – what is our purpose, and what goals do we have? What are the children's current interests and needs? Are all the children represented in these activities?
- Ask yourself, does the tablet activity add something meaningful to the analogue work (not merely replacing it)?

Acknowledging the curriculum and the importance of dedicating time:

- Many areas of the curriculum can be integrated through digital activities, including STEM-related subjects. This can be advantageously included in various projects to make it more meaningful for the children.
- Dedicating the necessary time for the implementation of the work (from planning to implementation) is crucial.

Holding teacher workshops:

- If you are a more knowledgeable teacher and have experience and ideas when it comes to digitalization work, why not share your knowledge and experiences by hosting workshops for your colleagues in your school and community?
- For instance, one suggestion could be once a week in each work team and once a month with the entire preschool staff and principal.

16.5 Conclusions

Our research results indicate that digital tablets have great potential to be used as an educational resource—both in supporting preschool children's learning in general, as well as in STEM-related subjects. The study findings point to very meaningful, self-initiated, and rich activities implemented by teachers where tablets contribute to realizing curriculum mandates. At the same time, and in support of other findings in the literature, the integration of tablets has been welcomed by educators in preschool (Nilsen, 2018). Teachers use tablets for general and technology-related teaching activities, as well as specifically for programming activities. Findings also show that programming activities with tablets can be meaningfully integrated as part of multiple STEM activities (e.g., Fridberg & Redfors, 2021). Overall, many teachers opine that tablets provide increased conditions and opportunities for implementing pedagogically rewarding activities (Otterborn et al., 2019). There is also a genuine will from preschool teachers to actively develop this work. Overall, the current climate of teacher opinion revealed in this research bodes well for the future integration of digitalization into preschool pedagogical practice.

In addition, school managers and other decision-makers have an excellent opportunity to support and pursue this work by providing teachers with suitable conditions. They must ensure that educators are offered resources in the form of time for planning and implementation. Also, suitable tablet (and other digital) equipment is a prerequisite, in combination with technical support. Teachers also need supplementary training. General knowledge about digitalization is necessary, as well as insight into how to specifically use digital tablets in educational interventions (Falloon, 2020). This request is strongly in line with teachers' wishes revealed in our research, even from the more knowledgeable and experienced educators, who also express a desire for more collaboration with their colleagues in their digitalization work.

In the most recent 2019 Swedish preschool curriculum, digitalization integration that supports children's digital competence is deemed imperative. However, there are very few explicit descriptions in the official curriculum text about how to actually execute such integration in practice. Hence, guidelines will have to be generated by other role-players in the educational system. We believe that one solution could be to foster closer dialogue between ICT representatives (e.g., preschool teachers responsible for ICT) and school management, which might yield systematic guidelines for digitalization work. Here, the work could be further complemented in collaboration with researchers to identify further meaningful directives that teachers currently seek. From a research perspective, teachers can employ an action research approach (on their own, as a common learning process) to study, transform, and develop educational technology activities (e.g., Fink, 2018). Here, teachers can commence from multiple questions, such as: How can we support children in developing digital competence? How can we use digital tablets to complement different projects and theme work in different subjects? How can we explore whether such digital tools really add and improve pedagogy and not merely replace already meaningful analogue tools? And, how can we ensure that educational technology enhances children's play, development, and learning? Implementation of suggested educational actions (e.g., changes in working methods and/or in the environment or development of common goals and objectives) must be based on scientific knowledge. Scientifically and critically based discussions on working with emerging educational technologies should occur regularly.

References

Ackermann, E. (2001). Piaget's constructivism, Papert's constructionism: What's the difference. *Future of Learning Group Publication, 5*(3), 438.

Benton, L., Saunders, P., Kalas, I., Hoyles, C., & Noss, R. (2018). Designing for learning mathematics through programming: A case study of pupils engaging with place value. *International Journal of Child-Computer Interaction, 16*, 68–76.

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.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers and Education, 72*, 145–157.

Bers, M. U. (2018). *Coding as a playground: Programming and computational thinking in the early childhood classroom.* Routledge.

Cederqvist, A. M. (2020). Pupils' ways of understanding programmed technological solutions when analysing structure and function. *Education and Information Technologies, 25*(2), 1039–1065.

Common Sense Media, & Rideout, V. (2011). *Zero to eight: Children's media use in America.* Common Sense Media.

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.

Elvstrand, H., Hallström, J., & Hellberg, K. (2018). Vad är Teknik? Pedagogers uppfattningar om och erfarenheter av teknik och teknikundervisning i förskolan. *Nordic Studies in Science Education, 14*(1), 37–53.

Faber, H. H., Wierdsma, M. D. M., Doornbos, R. P., van der Ven, J. S., & de Vette, K. (2017). Teaching computational thinking to primary school students via unplugged programming lessons. *Journal of the European Teacher Education Network, 12*, 13–24.

Falloon, G. (2013). Young students using iPads: App design and content influences on their learning pathways. *Computers & Education, 68*, 505–521.

Falloon, G. (2014). What´s going on behind the screens? Researching young students' learning pathways using iPads. *Journal of Computer Assisted Learning, 30*(4), 318–336.

Falloon, G. (2020). From digital literacy to digital competence: The teacher digital competency (TDC) framework. *Educational Technology Research and Development*, 1–24.

Fink, M. (2018). *Effective iPad integration in the kindergarten literacy curriculum through creation-based literacy tasks: An action research study* (Doctoral dissertation, University of Pittsburgh).

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.

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*, 1–15.

Gomes, T. C., Pontual Falcão, T., de Azevedo, C., & Restelli Tedesco, P. (2018). Exploring an approach based on digital games for teaching programming concepts to young children. *International Journal of Child-Computer Interaction, 16*, 77–84.

Hallström, J., & Schönborn, K.J. (2019). Models and modelling for authentic STEM education: Reinforcing the argument. *International Journal of STEM Education, 6*(22).

Heikkilä, M., & Mannila, L. (2018). Debugging in programming as a multimodal practice in early childhood education settings. *Multimodal Technologies and Interaction, 2*(3), 42.

Kjällander, S., & Riddersporre, B. (red.) (2019). *Digitalisering i förskolan: på vetenskaplig grund*. (Första utgåvan). [Stockholm]: Natur & Kultur.

Kress, G. (2003). *Literacy in the new media age.* Routledge.

Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? *Computers in Human Behavior, 41*, 51–61.

Mannila, L. (2017). *Att undervisa i programmering i skolan: varför, vad och hur?* Lund: Studentlitteratur.

Marklund, L. (2019). Swedish preschool teachers' perceptions about digital play in a workplace-learning context. *Early Years*, 1–15.

Marklund, L. (2020). Swedish preschool teachers' experiences from pedagogical use of digital play. *Journal of Early Childhood Education Research, 9*(1), 171–193.

Mertala, P. (2019). Young children's conceptions of computers, code, and the Internet. *International Journal of Child-Computer Interaction, 19*, 56–66.

Neumann, M. M., & Neumann, D. L. (2014). Touch screen tablets and emergent literacy. *Early Childhood Education Journal, 42*(4), 231–239.
Nilsen, M. (2018). *Barns och lärares aktiviteter med datorplattor och appar i förskolan.* Doctoral thesis, University of Gothenburg.
Otterborn, A., Schönborn, K., & Hultén, M. (2019). Surveying preschool teachers' use of digital tablets: General and technology education related findings. *International Journal of Technology and Design Education, 29*(4), 717–737.
Otterborn, A., Schönborn, K., & Hultén, M. (2020). Investigating preschool educators' implementation of computer programming in their teaching practice. *Early Childhood Education Journal, 48*, 253–262.
Palmér, H. (2015). Using tablet computers in preschool: How does the design of applications influence participation, interaction and dialogues? *International Journal of Early Years Education, 23*(4), 365–381.
Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* Basic books.
Petersen, P. (2015). "That's how much I can do!" Children's agency in digital tablet activities in a Swedish preschool environment. *Nordic Journal of Digital Literacy, 10*(3), 145–169.
Popat, S., & Starkey, L. (2019). Learning to code or coding to learn? A systematic review. *Computers & Education, 128*, 365–376.
Robson, C., & McCartan, K. (2016). *Real world research: A resource for users of social research methods in applied settings.* Wiley.
Rosén, M. (2011, 24 november). Datorer får barn att läsa mindre [Video file]. Retrieved from https://www.youtube.com/watch?v=xkVcn 0ZmpMg.
Selwyn, N., Hillman, T., Eynon, R., Ferreira, G., Knox, J., Macgilchrist, F., & Sancho-Gil, J. M. (2020). What's next for Ed-Tech? Critical hopes and concerns for the 2020s.
Skolinspektionen. (2017). *Förskolans arbete med matematik, teknik och naturvetenskap [Elektronisk resurs].* Skolinspektionen.
Skolverket. (2018a). *Läroplan för förskolan: Lpfö 18.* Stockholm: Skolverket.
Skolverket. (2018b). *Programmering i skolan.* https://www.youtube.com/watch?v=0_jBxUlh0zY&t=157s
Stables, K. (1997). Critical issues to consider when introducing technology education into the curriculum of young learners. *Journal of Technology Education, 8*(2), 50–66.
Sundqvist, P. (2019). *Förskolans teknikundervisning: vad och hur?* (Doctoral thesis: Studies in Educational Sciences: 42) Västerås: Mälardalens högskola.
Walldén Hillström, K. (2014). *I samspel med surfplattor: om barns digitala kompetenser och tillträde till digitala aktiviteter i förskolan* (Licentiatuppsats, Pedagogisk forskning i Uppsala, 167).

Anna Otterborn is a Ph.D. student at Örebro University and an experienced preschool teacher that received her Ph.Lic. (Licentiate) at the Swedish national graduate school in science and technology education (FontD), Linköping University. Her research focuses on digitalization in preschool.

Konrad Schönborn is a professor of visual learning and communication at Linköping University, and scientific leader of the Swedish national graduate school in science and technology education (FontD).

Part V
Conclusion

Chapter 17
Tools for Improving Learning and Teaching in Design and Technologies Education

Belinda von Mengersen and P. John Williams

In each of the chapters, you will note a section near the conclusions under the sub-heading:

How this might be used to improve teaching and learning. In these sections the authors have carefully considered how their colleagues could apply some of the research findings to their own teaching practice. This chapter is a glossary which can provide a quick reference guide for readers who are interested in considering this wide range of tools for learning and teaching. Each glossary entry will provide a short chapter summary, and some key terms and references.

Developing Leadership in Design and Technologies Education

Chapter 2, Paul Mburu

This chapter discusses the variability of design and technologies department leadership within schools and asks the question about how these leaders undertook their mentorship roles. In particular, the author focusses on how the mentor's role supports the teacher's interpretation and implementation of a Design and Technologies national curriculum. The researcher acknowledges the challenges faced by a department or subject leader due to the diversity of sub-discipline areas studied under the umbrella term of Design and Technologies education, and acknowledges that a variety of pedagogical approaches are used in any one department, depending upon the context, these approaches are also influenced by other factors including school-based policies, perceived "status" of the discipline within the school, and parental and student perceptions of the discipline. The research considers the role of these leaders and considers tools they use (refer to a list of these in the chapter under the

B. von Mengersen (✉)
Australian Catholic University, 25A Barker Road, Strathfield, NSW 2135, Australia
e-mail: belinda.vonmengersen@acu.edu.au

P. John Williams
Curtin University, Kent St, Bently, WA 6102, Australia

P. J. Williams and B. von Mengersen (eds.), *Applications of Research in Technology Education*, Contemporary Issues in Technology Education,
https://doi.org/10.1007/978-981-16-7885-1_17

sub-heading: Monitoring teaching and learning) to sustain and encourage teachers (refer to "building relationships") and how they advocate for their discipline within the school (refer to showcasing Design and Technology). One of the significant findings in this research was that "although tools appeared to be the same, subject leaders appropriated them differently" and that the leader's ability to provide opportunities for dialogue supported pedagogical development when "a collective approach and debates on teaching and learning were enhanced by subject leader's working practices, for example, through department meetings and sustained informal conversations". As we have seen echoed in other chapters, the leaders "held complex understandings on why and how Design and Technology mattered" and their ability to communicate this influenced how the discipline was perceived by students, staff and parents.

Key references on communicating the values of Design and Technology Education:

- Hardy, A. (2015a) What's D&T for? Gathering and comparing the values of design and technology academics and trainee teachers. Design and Technology Education: An International Journal, 20 (2), 10–21.

The Formation of Science, Technology, Engineering and Mathematics Teacher Identities: Pre-service Teacher's Perceptions

Chapter 3, Dawne Irving-Bell

This chapter explores the development of pre-service teacher self-efficacy in Design and Technologies education. Asking: What are some of the factors which influence a teacher's perceptions and value of design and technologies as a discipline? How are their perceptions "shaped by their previous experiences of learning?" The key finding in this research is that pre-service teachers assign meanings to their own lived experiences that are significant in their development as teachers. The researcher then asked what motivates their decision to become a teacher? And how does an understanding of the relationship between personal beliefs and teaching behaviours inform our encouragement of pre-service teachers in design and technologies education? In this study it was observed that a participant who perceived themselves as having "weak subject knowledge" felt limited in their options for pedagogical approaches in that area, they felt that they did not have the necessary knowledge that might afford them the opportunity to use an innovative pedagogical approach or take any perceived pedagogical risks in their learning design or delivery. Pre-service teachers who believed that they had weak subject knowledge in a particular area "were more inclined to deliver lessons which were procedural" (refer to Fig. 3.1 The Subject Knowledge Gap: Impact on Pedagogy and Identity). The researcher goes on to ask how teachers might reflect upon their practice and develop the courage to use alternative pedagogical approaches. In this way, the research findings are relevant not only in the pre-service teacher phase but throughout a teaching career, as teaching in the discipline Design and Technologies requires a capacity to reflect, learn and adapt, to an ever-evolving area (refer to Fig. 3.2. Mentoring beyond the comfort zone).

Key references on co-creation in learning and teaching and risk-taking in the classroom:

- Bovill, C. (2020). Co-creation in learning and teaching: the case for a whole-class approach in higher education. Higher education 79, 1023–1037. http://doi.org/10.1007/s10734-01900453-w.
- Irving-Bell, D. (2019). Risk taking in the classroom—Moving teachers forward from pedestrian to innovative practice. In Mentoring Design and Technology Teachers in the Secondary School: A Practical Guide (1st ed., pp. 142–153). (Mentoring Design and Technology Teachers in the Secondary School). Routledge. https://doi.org/10.4324/9781351011976-12.

Strategies for Responding to Curriculum

Chapter 4, Elizabeth Reinsfield

The author considers the difference between how teachers interpret curriculum concepts and how they enact them, encouraging teachers to consider creative pedagogical approaches that foster creative and critical thinking and encourage problem-solving in learning and teaching. The research indicated that some teachers "communicate historical understandings of the nature of technology education" resulting in a disconnect between curriculum interpretation (theory) and application (practice). It was shown that when a teacher was able to "access professional learning outside of their immediate context" they were more encouraged to take pedagogical risks and explore new approaches, refer to Fig. 4.2 Navigating troublesome curriculum knowledge. The research indicates that professional opportunities can result in a conceptual transition for teachers that enables them to enter dialogue with students to establish clear learning goals and communicate a more adaptive understanding of the breadth of technology education concepts, refer to Fig. 4.4 Strategies to address technology teachers' enactment of the curriculum.

Key references for exploring concepts of technological literacy:

- Dakers, J. (2006). Defining technological literacy: Towards an epistemological framework. Palgrave MacMillan.
- Williams, P. J. (2009). Technological literacy: A multiliteracies approach for democracy. International Journal of Technology and Design Education, 19(3), 237–254. https://doi.org/10.1007/s10798-007-9046-0.

Enacting Technology Education: Investigating the Relationship Between Goals for Teaching Technology and Enacted Practices

Chapter 5, Andrew Doyle

In this chapter the author considers the space between a teachers' "ideal" degree of technological literacy (and resulting self-efficacy), and their day-to-day struggles to embody this ideal. A framework is provided here (refer to Fig. 5.1) that encourages teachers to "analyse and articulate" their own practice (in particular, gaps between "knowledge" and "activity") and develop personal conceptual goals that aim to answer "why" we teach technology. The author recommends educators take into consideration the variable contextual perspectives of technology education which can range from a national curriculum focussed on developing principles of user-centred design through to vocationally oriented technical skill development. This method provides them with an opportunity to consider the overlap between their beliefs and knowledge and conceptualise how these factors influence their teaching.

Key references:

- For the framework, analysis of gaps between "beliefs and knowledge" refer to Fig. 5.1. Ecologically situated model of enacted practice, teacher beliefs and knowledge Doyle, A., Seery, N., & Gumaelius, L. (2019).
- Operationalising pedagogical content knowledge research in technology education: Considerations for methodological approaches to exploring enacted practice. British Educational Research Journal, 45(4), 755–769.
- And when considering personal goals responding to the "why" we teach technology, refer to Fig. 5.2. Grounded theory of the purposes of teaching technology.

Enhancing Elementary Teacher Practice Through Technological/Engineering Design-Based Learning

Chapter 6, Anita S. Deck

In this chapter the author outlines ways to introduce younger students to design-based learning through the design-based principles of engineering. The author has considered how Technological/Engineering Design-Based Learning (T/E DBL) approaches can be used in integrative STEM education contexts. This research indicates that Design-Based learning approaches can also assist educators who don't feel confident, in all discipline areas under the STEM umbrella. Design-Based Learning has been "found to be an effective approach in science education" because it provides a contextualised approach and is thus perceived by students and teachers to be more meaningful. In this study the T/E DBL approaches were introduced through a professional development intervention, and results indicated that "participants were better able to integrate T/E DBL when planning and designing instructional units and demonstrated an improved understanding of the science concepts they were teaching". The author makes suggestions for how the outcome of this study might be used to improve teaching and learning, including: 1. By using "an authentic engineering design challenge using the PIRPOSAL model, teachers are more able to design units that promote higher-order thinking and intentionally teach science" and "rather than teaching isolated concepts" both teachers and learners can integrate prior knowledge, 2. That professional development experiences need to be tailored to address concerns educators may have about implementing a new pedagogical approach.

Key references supporting the use of engineering pedagogical learning models in science contexts and integrative STEM education:

- Ercan1, E., & Sahin, F. (2015). The usage of engineering practices in science education: Effects of design-based science learning on students' academic achievement. Necatibey Faculty of Education, 9(1), 128–164.
- Wells, J. G. (2016) PIRPOSAL model of integrative STEM education: Conceptual and pedagogical framework for classroom implementation. Technology and Engineering Teacher, 75(6), 12–19.

Teaching and Learning Science Through Design Activities

Chapter 7, Dave van Breukelen

This chapter develops strategies for interdisciplinary learning, in particular enhancing learning and teaching in a traditional subject like science through design thinking and design activities. The author describes some of the benefits of Design-based Learning (refer to Table 7.1 LBD's (Learning by Design) stages and activities) as providing students with an opportunity to apply their knowledge to a complex problem or designed system guided by design-based teaching strategies. Strategies where "the dynamic learning process" is broken-down or scaffolded (refer to Table 7.2 LBD (re)modifications) enabling teachers to assess students understanding) and provide students with an opportunity to develop skills in design-based strategies that can be re-contextualised. In Table 7.3 the author has developed a table to guide educators learning and teaching approaches in Design-Based Learning which support the learning design models outlined in the previous tables (refer to Table 7.3, Learning-related interactions, and teaching strategies).

Key references:

- Refer to the models included in the chapter for an overview of scaffolds that can be used by teachers: see Fig. 7.1, Overview of studies; Fig. 7.2, Curriculum approach for DBL; Fig. 7.3, Learning task construction through iterative backward design; and Fig. 7.4, FITS model and (re) modifications.
- Teaching in multi-disciplinary contexts, Rennie, L., Venville, G., & Wallace, J. (2012). Integrating science, technology, engineering, and mathematics. New York, NY: Routledge.

Principles of Human-Centered Design: Developing Values in Design

Chapter 8, Neshane Harvey and Piet Ankiewicz

In this chapter, the authors define design and technologies as being "value-laden" and focus on how value is developed through principles of Human-Centered Design (HCD), placing the needs of people at the centre of a design problem. From a pedagogical perspective, they consider how a co-design approach can support Human-Centred Design strategies and enable the development of a student's value structure in response to Design and Technologies Education through collaboration. Historically, in the fashion discipline an individualistic pedagogical approach has been applied, perpetuating the mythology of the "hero-designer". The key research findings outline several strategies that enable the development of a co-design approach to designing in response to an identified Human-Centred design need or problem. In this study, the student-designers were required to co-design with a user and respond to the specific needs of that user. Some key findings were the “benefits of design with users illustrate new insights, thinking, inclusivity, collaboration, and shared decision-making” and “inclusivity, collaboration, and joint decision-making occurred across the design process resulting in informed decision-making”.

Key reference which explores the development of value concepts in design and technology education:

- Pavlova, M. (2005). Knowledge and values in technology education. International Journal of Technology and Design Education, 15(2):127–147.

Effective Use of Engineering Design Principles and Processes

Chapter 9, Euisuk Sung

In this chapter the author asks: Why are so many of the principles of engineering design used in design and technology education? An initial answer is Design and Technologies role in STEM and many evolving national curriculums requiring an understanding of engineering principles and systems. The researcher considers links between engineering design methods and others commonly used in design and technologies education, defining an engineering design process as: “an iterative process of devising a system, component, or strategy to meet desired needs”. The researcher initially analysed “existing engineering design process models presented by textbooks and researchers”, then developed a design process model derived from the study. This author outlines practical suggestions for teachers on “the use of the engineering design process in the classroom” where “active” learners can participate in iterative design development, and the “primary function of educators is to facilitate student learning by constructive learning environment” (refer to the four ways that this research can be used to improve teaching and learning: 1. Consider how much time is spend on designing and modelling, 2. How modelling can be used as a mental tool, 3. The difference between problem versus solution-oriented approaches, 4. The benefits of stressing an iterative design process, and 5. The importance of inquiry in engineering design thinking (such as designing, predicting and modelling).

The key findings of this study are that “students use various cognitive strategies, including framing problems, analysing and formulating questions, ideations, modelling, and self-regulation, and managing the group performance in the process of engineering design”.

Key reference:

- A revised set of International Standards for technological and engineering literacy: International Technology and Engineering Education Association (ITEEA). (2020). Standards for technological and engineering literacy: The role of technology and engineering in STEM education. Reston, VA: Author.

Developing Critical Thinking Through Real-World Design Problems

Chapter 10, Susheela Shanta

This chapter considers how students' metacognitive skills including the ability to become critical thinkers are enhanced in STEM projects that integrate Engineering. However, that students are often assessed on the "'correctness' of the end-result and rarely, if ever on the reasoning or procedures leading to the result" (Docktor & Heller, 2009; Shavelson, Ruiz-Primo, Li & Ayala, 2003; Steif & Dantzler, 2005). Engineering and STEM projects provide students with "hands-on and design-oriented approach" to learning that can enable metacognitive awareness including their ability to become more critical thinkers. This research provides teachers with a tool—in the form of a rubric (refer to Fig. 10.3 Final modified scoring rubric)—that can help assess "student problem-solving skills when faced with an authentic design challenge" or the types of design thinking. Thinking that can be elusive in traditional assessment practices as "students engage in their own unique and sometimes ad-hoc trajectories in defining a problem and set about developing alternative solutions" and usually requires subjective evaluation. The author encourages teachers to develop students' critical design thinking by "selecting a design challenge that is based on real-world problems" and by "creating an intentional focus on developing the five skills identified" in the rubric. As indicated in the rubric criteria this study identified four specific abilities "related to students' performance in authentic problem-solving. The four specific abilities are—Sketching, Specific Application of Physics, Application of Mathematics, and Logical Progression".

Key references related to the aim of enhancing and assessing "conceptual attainment" and "problem solving":

- Zuga, K. F. (2000). Thoughts on technology education research. Proceedings of the First AAAS Technology Education Research Conference, Washington, DC.

Developing Spatial Ability in the Classroom

Chapter 11, Jeffrey Buckley, Niall Seery, Donal Canty, and Lena Gumaelius

The authors have confirmed that developing spatial ability in the classroom can be achieved "through targeted interventions", for example "the intervention developed by Sorby, a designed intervention with specific timeframe and activities". The authors stress that whilst "the use of CAD has the capacity to both supplement a student in visualising a thought or idea and prevent the need for a student to mentally generate an image as the technology can do this for them". They suggest that a useful pedagogical scaffold for developing these skills is provided by Johnston-Wilder and Mason, in this process students "visualise their thinking prior to working with CAD".

Key references:

- Sorby's Targeted intervention model: Sorby, S., Veurink, N., & Streiner, S. (2018). Does spatial skills instruction improve STEM outcomes? The answer is "yes." Learning and Individual Differences, 67(1), 209–222. https://doi.org/10.1016/j.lindif.2018.09.001.

- Johnston-Wilder and Mason model for effecting learning, see Fig. 4, from Johnston-Wilder, S., & Mason, J. (2005). Developing thinking in geometry. SAGE Publications.
- See literature review Buckley, J., Seery, N., & Canty, D. (2018a). A heuristic framework of spatial ability: A review and synthesis of spatial factor literature to support its translation into STEM education. Educational Psychology Review, 30(3), 947–972. https://doi.org/10.1007/s10648-018-9432-z.

Assessment for Learning, Developing Teacher and Student Partnerships

Chapter 12, Chandan Boodhoo

This chapter focusses on assessment as a tool for learning and encourages educators to consider how teacher/student partnerships benefit learning and teaching. The author reminds us that "for assessment to be effective, it should have the following features: useful, targeted, and sustainable", but that an educator understanding of principles of formative and summative assessment, and their perception of its role will affect how it is designed and delivered. The author outlines a definition of assessment for learning that relies upon dialogue and discussions which clarify "learning intentions and criteria", as well as providing feedback with the overarching intention of encouraging the student to reflect upon their own learning (refer to Fig. 12.1, A sample of the rubric table used as a guideline to identify "assessment for learning" categories). One key awareness is that if the time allowed students to formulate a response to a teacher's question is inadequate (five to six seconds as an absolute minimum) then the dialogic approach that underpins assessment for learning principles can be compromised. This study encourages teachers "to promote a thinking classroom" indicating that this "can be achieved by asking good questions, and by encouraging students to express themselves and reflect on their ideas". Another point raised was that a teacher often only "recorded superficial information concerning students' difficulties", which is less useful for supporting assessment for learning which focusses on constructivist rather than behaviourist perspectives.

Key references in assessment for learning literature:

- Barnes, N., Fives, H., & Dacey, C. M. (2015). Teachers' beliefs about assessment. In H. Fives & M. G. Gill (Eds.), International handbook of research on teachers' beliefs (pp. 284–300). Routledge.
- Poskitt, J. (2014). Transforming professional learning and practice in assessment for learning. The Curriculum Journal, 25(4), 542–566. https://doi.org/10.1080/09585176.2014.981557.

Integrating Design and Technology with Entrepreneurship in Lesotho

Chapter 13, Nthoesele Mohlomi

In this chapter the author discusses the link between developing skills in Entrepreneurship within a Design and Technologies Educational context. Many national curriculums encourage the "integration of entrepreneurship concepts" and ask educators to link to the relevance of technological learning and problem-solving to broader societal problems and focus on potential vocational application of knowledge and skills developed through design and technologies education. In this project, students are encouraged to look at their own community and consider potential entrepreneurial opportunities. Specific strategies to improve teaching and learning of design and technology with entrepreneurship have been developed (refer to Table 13.1, Summary of Strategies, and their intention). Further, the chapter identifies particular student behaviours associated with the development of entrepreneurship skills (refer to Table 13.2, D&T with Entrepreneurship skills and the behaviour/actions to look for to identify a learner's skill inclination), the researcher suggests that observing the development of these skills through a number of open-ended design projects where the teacher can implement one or more of the strategies, for example (strategy five identifies personality, where the teacher can observe a student's disposition and compare them to the traits listed).

Key reference, for an overview of the concept of academagogical:

- Jones, C., Penaluna, K. & Penaluna, A. (2019). The promise of andragogy, heutagogy and academagogy to enterprise and entrepreneurship education pedagogy. International Institute for Creative Entrepreneurial Development, University of Wales Trinity Saint David, Carmarthen, UK.

Technology Education in a Play-Based Preschool

Chapter 14, Pernilla Sundqvist

This chapter broaches the question of how to "teach" the principles of design and technology education in a play-based pedagogical environment where teachers describe having "limited knowledge and confidence in technology". The researcher found that in this instance the subject was taught very differently and that it was dependent upon those teachers philosophical understanding of the subject. Contextual reasons for the variability of learning and teaching practices and interpretations are outlined in the chapter, and the researcher sought to examine the range of possible content, how it is currently being taught (refer to Table 14.1, Overview of the results) and how the discipline is perceived by the teachers (refer to the list of six ways to characterise technology education in the chapter). The two key findings of the research are 1. That it was "not clear to all preschool staff what technology is and what should be taught" and 2. Neither was it clear how they should "teach technological content in a play-based preschool". The researcher proposes that a clear distinction between Information Communication Technologies and Design and Technologies also needed to be clarified in this context. Further, they suggest pedagogical approaches that would be considered compatible with a play-based preschool environment including "exploring, investigating, and creating technological objects and systems", including describing example activities and discussing practical ways that a revised perception of the benefits of technological learning could be developed in this context.

Key references on defining the breadth of technological knowledge and its contextual applications to learning:

- Benenson, G. (2001). The unrealized potential of everyday technology as a context for learning. Journal of Research in Science Teaching, 38(7), s. 730–745.
- Hansson, S. (2013). What is Technological Knowledge? In I.-B. Skogh & M. J.de Vries (Eds.) Technology Teachers as Researchers, 17–31, International Technology Education Studies: Sense Publishers.

Integrating Indigenous Technologies

Chapter 15, Richard Maluleke and Mishack T Gumbo

This chapter provides a rich set of pedagogical approaches that have responded to very specific cultural contexts, in particular focussing on providing students with opportunities to learn from indigenous technologies. Many curriculums acknowledge the inclusion of indigenous technologies, however, to be effective and understood by teachers and learners the knowledge (theory) and practice (application) need to be culturally relevant which often requires the development of clear links between historical and contemporary indigenous technologies. This chapter describes how carefully curated examples that implement opportunities for the students to investigate indigenous technologies in particular contexts can result in very meaningful learning experiences for students. Whereby they develop an understanding of the properties of local materials and skills for design and manufacture. The research indicated that "indigenous learners are curious about indigenous technology and the skills used to make indigenous artifacts" and "their knowledge retention and skills last longer if their learning is inspired by curiosity". In this way an introduction to indigenous technologies can foster a student's inclination towards and ability to design and manufacture products, refer to Fig. 15.4. Indigenous technology-based design process (ITbDP)

Key references on approaches to the inclusion of indigenous technologies into curriculum, learning and teaching in design and technology education:

- Biraimah, L.B. (2016). Moving beyond a deconstructive past to a decolonised and inclusive future: The role of ubuntu-style education in providing culturally relevant pedagogy for Namibia. Internationally Review of Education, 62(1): 45–62.
- Gumbo, M.T. (2015). Indigenous technology in Technology Education curricula and teaching. In Williams, P.J., Jones, A. & Bunting, C. (Eds.). Contemporary issues in Technology Education: The future of Technology Education. Hamilton: Springer.

Implementing Digital Tablet Activities in Swedish Preschool Education

Chapter 16, Anna Otterborn

Design activities suitable for preschool learners where educators use digital tablets as an interface are considered in this chapter. Use of digital tablets in this context relates to developing active learning experiences through design (in programming for example) in a STEM context rather than passive learning experiences of sourcing information about a topic or documenting their analogue work through photography. The researchers found that "teachers have a genuine desire to develop pedagogical initiatives with digital tablets, and many creative activities and interventions emerged", for a list of the types of activities considered please refer to Fig. 16.1, and Table 16.1 for examples of technology content areas and related tablet activities with corresponding apps used at the preschool level in Sweden. This chapter provides examples where "children explore how simple technologies function, as well as develop their ability to build, create, and construct" and demonstrated that teachers "combine unplugged and digital programming, often commencing with unplugged programming", for instance, using physical activities like yoga to help understand how to communicate instructions of how to move to a robot. A set of learning goals has been outlined in Table 16.2, Three overall clusters of learning goals connected to preschool programming activities in Sweden and list of practical advice for preschool educators use of tablets during teaching.

Key references:

- Developing digital competence including programming in pre-schooler's: Otterborn, A., Schönborn, K., & Hultén, M. (2019). Surveying preschool teachers' use of digital tablets: general and technology education related findings. International Journal of Technology and Design Education, 29(4), 717–737.
- Otterborn, A., Schönborn, K., & Hultén, M. (2020). Investigating preschool educators' implementation of computer programming in their teaching practice. Early Childhood Education Journal, 48, 253–262.

Belinda von Mengersen is a specialist in traditional, current and emerging textile technologies, and leads Design and Technologies at the National School of Arts, Australian Catholic University. She has authored chapters in three volumes of Springer's Contemporary Issues in Technology series, regularly reviews articles for the International Journal of Technology and Design Education and presents frequently at International Design and Technologies conferences including PATT, TERC and DAATArc. Belinda focuses on reflective, creative and speculative writing in design practice, practice-led research in design, the intersection between signature pedagogies of visual arts, design and technology, and the dynamic and interdisciplinary nature of design-related fields.

P. John Williams is a Professor of Education and the Director of Graduate Research in the School of Education at Curtin University in Perth, Western Australia, where he teaches and supervises research students in STEM and technology education. Apart from Australia, he has worked and studied in a number of African and Indian Ocean countries and in New Zealand and the United States. His current research interests include STEM, mentoring beginning teachers, PCK

and electronic assessment of performance. He regularly presents at international and national conferences, consults on Technology Education in a number of countries, and is a longstanding member of eight professional associations. He is the series editor of the Springer *Contemporary Issues in Technology Education* and is on the editorial board of six professional journals. He has authored or contributed to over 250 publications, and is elected to the International Technology and Engineering Education Association's Academy of Fellows for prominence in the profession.