Innovations in Science Education and Technology 23

Martin Riopel
Zacharoula Smyrnaiou *Editors*

New Developments in Science and Technology Education

Springer

Innovations in Science Education and Technology

Volume 23

Series editor
Cohen, Karen C.
Weston, MA, USA

As technology rapidly matures and impacts on our ability to understand science as well as on the process of science education, this series focuses on in-depth treatment of topics related to our common goal: global improvement in science education. Each research-based book is written by and for researchers, faculty, teachers, students, and educational technologists. Diverse in content and scope, they reflect the increasingly interdisciplinary and multidisciplinary approaches required to effect change and improvement in teaching, policy, and practice and provide an understanding of the use and role of the technologies in bringing benefit globally to all.

More information about this series at http://www.springer.com/series/6150

Martin Riopel • Zacharoula Smyrnaiou
Editors

New Developments in Science and Technology Education

Springer

Editors
Martin Riopel
Département de didactique
Université du Québec à Montréal
Montréal, QC, Canada

Zacharoula Smyrnaiou
University of Athens
National and Kapodistrian
Zografou, Greece

ISSN 1873-1058 ISSN 2213-2236 (electronic)
Innovations in Science Education and Technology
ISBN 978-3-319-22932-4 ISBN 978-3-319-22933-1 (eBook)
DOI 10.1007/978-3-319-22933-1

Library of Congress Control Number: 2016932307

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer International Publishing AG Switzerland.

Preface

Science and technology education research, influenced by inquiry-based thinking, not only concentrates on the teaching of science concepts and addressing misconceptions that learners may hold, but also emphasizes how students learn and tries to find out ways to achieve better learning through creative ways. New developments in science and technology education rely on a wide variety of methods, borrowed from many other sciences such as computer science, cognitive science, sociology and neurosciences.

This book presents papers from the First International Conference on *New Developments in Science and Technology Education* (1st NDSTE) that was structured around four main thematic axes as follows: Modern Pedagogies in Science and Technology Education, New Technologies in Science and Technology Education, Teaching and Learning in the Light of Inquiry learning Methods and Interest, Attitude and Motivation in Science.

The fundamental aim of the book is to explore the beneficial impact of pedagogically updated practices and approaches in the teaching of science concepts as well as to elaborate on future challenges or emerging issues that address Science and Technology Education. By pointing out on new research directions, we manage to inform educational practices and bridge the gap between research and practice providing information, ideas and new perspectives. The book also aims to inform as well as to promote discussions and networking among scientists and stakeholders from worldwide scientific field such as researchers, professors, students and companies developing educational software and ICT tools.

Contents

Part I
Fundamental Issues in Science Education

Introduction

The first part of this book is called ‘fundamental issues in science education’. The contributions address this theme by premising that unraveling persisting issues for science education may require new angles, both to examine challenges in new ways and also to rethink issues in new ways. Topics such as science identity, collaborative learning in science, science and assessment, neuroscience in science education research, gender and science topics and interest in science are important issues in current research in science education. The chapters build on existing discourse that includes social, cultural and historical aspects but also research contributions that come from fields that are still new for science education research.

Constructing yourself in school science examines subjectivity as its central theme, to think about how young people construct, produce and see themselves when they are part of the classroom community in science. By building on philosophers including Bruno Latour who argues that ‘humans and nonhumans’, including technology, are enmeshed with each other “the article is problematizing digital technology in science classrooms”. It is discussed that technology is not value free and contributes to the expectations that society, school, teachers and students carry into the classroom and contributed how young people see themselves in science.

The next chapter entitled *Learning Science in a Collaborative and Technological Environment* revisits the issue that learning in science classrooms is not addressed by simply equipping schools with new technology but by arguing that a mindful stringing together of pedagogy, content and technology is needed. The author focuses on collaboration because it supports problem solving and underpins the premise that doing and thinking in science is not necessarily an activity done in isolation but one where scientists deliberately seek and work with their communities to be challenged, supported and take thinking further. The chapter is particularly interesting because it provides the insights of a teacher whose teaching environment is radically changed to address agency and power in his classroom to provide collaborative learning opportunities for all students.

Tracing Computer-Assisted Assessment for learning Capability in Greek Teachers explores teacher beliefs on assessment practices. Becoming an assessment capable teacher is an important issue because policy makers and governments place high value on the outcomes of compulsory education and especially in science and this is even more so the case with a strong move towards more computer-assisted assessment integration. The chapter reports the Greek pilot study that is part of an international study and shows the relevance of considering context and teacher experience. It is explained how teachers ideas about the different dimensions to assessment are shaped, especially if it is used to assess inquiry based science education, where learners are introduced to more than conceptual learning outcomes but also competencies with social dimensions.

The chapter *Brain Activity During Observation of Affective Pictures with Scientific Content* explores how neuroscience has made rapid advances in areas relevant to science education. While on first sight it seems far-fetched to make connections between neuroscience and learner experiences, the chapter describes that learning involves also visual and spatial perception, including the attention on objects and features, and amongst other things also reflections on emotional processes. These processes can be detected through neuroimaging techniques. This chapter contributes widening the debate on learning environments and how they could be designed to support learning processes.

For some time now science education research has highlighted gender related differences between interest in science subjects such as biology (girls) and physics (boys). The chapter titled *At the Very Root of the Development of Interest: Using Human Body Contexts to Improve Women's Emotional Engagement in Introductory Physics* is picking up on this important issue to discuss what impact it may have to consider the use of gender relevant contextual examples. Drawing on insights gained through psychophysiological data, the chapter presents how context selection to teach physics is connected to positive emotional engagement. Importantly the chapter argues that it is important to acknowledge "that not all students are intrinsically interested in physics" and that this may require selecting contexts that are also gender relevant.

The final chapter in part I is called *Interest and Disinterest from College Students for Higher Education in Sciences* and discusses the continuing issue of young people's declining interest in science. In an investigation that involved the participation of more than 1000 students of various pre-university college programs, the authors explored aspects such as interest and motivation for sciences in consideration of factors such as faculty influences as well as self-efficacy, self-determination, motivation and grade motivation. The chapter reports that science students share drivers such as grade motivation when are compared to non-science students. The chapter also reports that attitude towards science can depend on the tasks and ways science is taught.

Chapter 1
Constructing Your Self in School Science

Kathrin Otrel-Cass

1.1 Introduction

Currently there seems general consensus amongst policy makers that children, our future citizens, need to be knowledgeable of and competent in science, to contribute or become part of a highly qualified future work force [10, 11]. Young people's alignment or misalignment with subjects, such as science and mathematics, has been explained being due to individual strengths or deficiencies in the teaching and learning of concepts and development of competencies [8]. In the absence of success in subjects like science, young people tend to withdraw from identifying themselves with the ideas and identities connected with scientific rationality. Such feelings may be so strong that they lead to early exits from formal science education. It is not surprising then that there is interest in schools transforming their practices, amongst other approaches, through the implementation of more and more digital technology in the hope to make education more authentic, relevant and to build on young people's culture.

Some would argue that science classrooms are privileged places of the school curriculum [2] because they promote a particular understanding of the natural world and how it connects to technology and society over time [1]. However the significance of school science is not solely about learning and development of scientific knowledge, skills and competences but also how it fabricates a child's desire to become a scientifically literate citizen. This means that science classrooms are places where young people form their *subjectivity* in relation to school science's core values, which are situated within the cultural norms of school communities.

This article is interested to explore how the assemblage of values, norms and practices in education in general and science in particular together with the material

K. Otrel-Cass (✉)
Department for Learning and Philosophy, Aalborg University, Aalborg, Denmark
e-mail: cass@learning.aau.dk

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_1

arrangements and the affordances they present to teachers and their students contributes to fabricating young people's subjectivity [4]. Following an explanation of subjectivity and how this may be connected to digital technology, an analysis of selected episodes from New Zealand and Danish primary science classrooms is presented.

1.2 Subjectivity and Digital Technology

Subjectivity has been a central concept in philosophy, cultural and social studies [4, 7] and is described not as an autonomous quality but rather refers to how one's perception of self is shaped by the networks and communities in which one participates [17]. Latour takes this notion further in so far that he discusses how humans and nonhumans, including technology, are enmeshed with each other and explains that nonhumans carry agency with particular consequences [13]. This is of interest in the context of this article where subjectivity is explored by examining the environment of primary school classes, particularly digital technology and how it contributes to children's construction of self while being in the science classroom.

Amongst science education researchers, it has been accepted that some young people align their self with society's desired science values such as objectivity, agency and entrepreneurship while others distance themselves from these norms and ways of seeing and being in the world [19]. It is not uncommon that this is explained by ways of deficit theorizing identifying the underachievement of minority cultures [12] or poor communities [3].

It is no surprise therefore that there is excitement about the potential changes that might be achieved in late modern science classrooms through the sophisticated use of digital tools that allow classroom practices to expand beyond what has been traditionally possible [16]. The educational transformations that may result from using a range of digital tools can include accelerations of space and time [18], to the capturing, freeze framing, slowing down, or rewinding of instances, ideas and experiences. More than that, digital tools allow for transformations in networking and connecting between young people, their teachers and communities beyond the classroom. This article is interested in exploring what role digital tools may play when young people access, digest, process information that is 'placeless' [18] and how this shapes where they place themselves in respect to science.

1.3 Methodology and Context of the Examples

The article explores how digital tools contribute to identity formation [5] by adopting a Bakhtinian perspective. Such a position considers both the anticipation of what is to be expected and how this shapes the 'authoring of our own identity' [20]. Specifically this means that conversations in context, observations or interviews were examined to identify *voices* and the point of views they carry. This may become apparent through value judgments but also through intonation. A sociocultural position of learning [6, 22] underpins this argument in so far that digital tools are seen as cultural tools that are embedded in contexts that shape beliefs and ideas.

In all three projects, data was collected in classrooms through video-recorded observations, and included also interviews with teachers and students. The three projects were connected in so far that one lead to another, building on and developing ideas and understanding about digital technology in science classrooms. The following is a brief summary of the projects and the data used in this article.

SCIAnTICT – project: a two-year project (2009–2010) investigating the use of ICT in New Zealand primary science classrooms [15]. This article presents the transcript of an interview with students during the first year of this project.

NILSS – project: a two-year project (2011–2012) that explored how digitally supported networks assist inquiry learning in science classrooms [23]. This article presents the transcript of a Skype conversation between two of the project's teachers and an excerpt from an interview with one of the students in year one of this project.

NILSS-DK project: a one-year (2012) parallel continuation to the above NILSS project. Like in the New Zealand counterpart, the Danish study involved science teachers and their students and how they used technology in inquiry science. Data used in this article stems from observations and interviews, particularly of one group of students who were starting their investigation about space.

1.4 Findings

While each of the three examples portrays different aspects in the use of digital technology, they all have in common that they describe familiar situations in science classrooms. Each time, digital technology formed part of the sets of tools of the educational classroom cultures that contributed to the promotion of particular values and norms. For the analysis, key episodes were identified that responded to the questions raised in this article leading to the identification of three themes.

1.4.1 Digital Media Tools and the Dynamic Nature of Becoming Self in Science Classrooms

Today's young people – the *new* video generation is said to be transformed in how they communicate but also how they process information and identify themselves in it. This first example is from an episode where a teacher showed her students a video from a popular TV programme in the New Zealand SCIAnTICT project. What is presented here is an interview with a group of 12-year old students. The conversation followed the observation where the teacher showed the class a video produced by a national TV programme and showed a test of different soaps. It emphasized the 'scientific method' including the need to re-test experiments. For example, the video showed how long soap could last if it was repeatedly immersed in water. The video included also the review of a 'tester' family of four who ranked different types of soaps based on smell and feel. The following excerpt is from the interview with three students:

Interviewer	If you compared these two different kinds of testing, what is the difference between the soap in the water and the test of the different family members with the soap?
Girl 1	The family showed more favouriteness, like feel, touch, smell, the bathtub one. But the favourite one was probably not a good science experiment as much, it's more like what you think, your opinion.
Boy 1	That's an opinion thing but the other one is more logical.
Boy 2	Yeah: for me its good to have both.
Boy 1	And (.) what's wrong with having an opinion?
Interviewer	Mmm (.) Why do you think your teacher showed you this video?
Girl 2	U: :m To show us that there's different ways of testing and some results may be different. If you test it more than once, you might come up with a different result.

From the conversational exchange it becomes clear that the three students are aware of the rules and conventions including what is expected from them to learn from the video. They are aware that a concept such as 'testing' in the context of their science classroom carries stakes and specific expectations. But the video presented a popularized version of testing within which the students identified a multiplicity of voices. 'More scientific' is 'logic' while judging by 'favouriteness' or people's biased opinions is less scientific. The students were also aware that they were positioned as learners of science and having an 'opinion' carries a value in this context, one that is both 'good' but 'probably not a good science experiment'. Buckingham [5] writes that identity has dynamic and fluid qualities and is not fixed, and he comments that identity formation is constant process of negotiations and interactions (p. 6). In the conversation, the students examine the position of having and opinion in science, indicating such fluidity. In this particular video, which was produced for the general public, the students were also offered a popular way of communicating and talking about science, one that was deliberately playful. The video allowed for soft values such as how the soap feels and promoted a style of science communication that is beyond the traditional authoritarian style.

1.4.2 Fabricating Subjectivity Through Authentic Events

Science teaching has been critiqued for its lack of authenticity. The use of digital technology offers persuasive possibilities to bring more authenticity into the classroom, like in this next example where a teacher used Skype so his students could have a conversation with a 'real' scientist. The example from the NILSS project presents the transcribed Skype conversation between two of the project teachers where one explains the other how he orchestrated a discussions of his class of 13- and 14-year-old children with a scientist via Skype.

Teacher A: Oh, ok. Yeah, yeah. Cause when I did mine I did it a little bit differently; I mean, obviously we didn't have the person actually come in, I did it over Skype just like we are now, basically, except I put it up on the projector and I got the kids to come up and sit in the seat and ask individual questions of the expert. So I suppose it's a little bit different and the kids came up with their questions beforehand, so I had done, you know, a little bit of work. And what I did to prompt them was I actually gave them a video that was kind of far too difficult for them, really – it was kind of a year 11, year 12 Biology video about cells and of course, you know, that triggered a whole pile of questions from there because they didn't actually understand very much from it and they were basically seeking clarification from the expert about their questions.

Teacher B: Did you decide to show them a video that was too hard, to stimulate those questions?

Teacher A: Yeah, that was the idea, yeah. Because I could have shown them a much lower level, a year 9 video, but then I thought well, that's just going to teach them everything they need to know about cells, it's not really going to trigger interest and stuff. So this video went right into, you know, transcription and translation and proteins and stuff you wouldn't expect really a year nine kid to know anything about. So they came up with some really interesting questions about stuff … I was able to give her the questions the night before and she was able to sit down and think about the types of things and discuss with me basically as to what level of language she could use and all those sorts of things. So it was rigged in a way, you know, to succeed but given it was the first time I had ever done it, I think it was a good kind of entry thing. And I think in the future I would do the same – I would email the questions away to whoever it was so at least they had some sort of idea about what to expect.

The teachers here reflected on the merits of inviting a 'real' scientist' and how to prepare for this. Teacher A refers to the conversation being 'rigged', in parts because of the video he presented to the students to come up with exciting questions was one that was targeting higher level classes so the intention was to present the scientist as one who reveals new knowledge. The teacher mentions that if he had selected a topic that was appropriate to fit the curriculum level it may not have been as exciting whereas the intent here was to 'trigger interest and stuff'. This reception was later echoed when a student reflected in an interview:

Boy: It was kinda cool cause you get to talk to people who know what they are doing, yeah (.) and it was quite fun and everyone was listening.

The student identified the scientist as authority who 'knows what he is doing' and this resulted in paying respect and listening to what he had to say.

Hekman [9] analyzing the works of Foucault writes that "we are subject to the production of truth through power". He highlights Foucault's argument that discourse transmits power and that "it is in the practices of power that knowledge and power are linked". This short dialogue between the teachers illustrates how this arrangement using Skype was intended to fabricate a particular type of discourse intended to affect students' self.

1.4.3 Distancing One Self – Counter Digital Subjectivity

There still exists the notion that *all* young people are inherently capable of using and accessing digital technology and more than that love to use all digital technology. The use of digital tools in classrooms is hailed as the natural answer to dealing with unenthusiastic young people. And while many young people are undoubtedly attracted to the powerful ways of technology there are examples of children who choose not do do so [5].

This is now illustrated through two short examples: in the SCIAnTICT project, the group of three girls, Deepti, Lisa and Mandy, are working on a project investigating rust. The three have organised themselves into: one who searches for information on the Internet (Deepti), one who conducts the experiment and collects the data (Lisa) and one who searches for information reading books (Mandy). Both Mandy and Lisa regularly visit Deepti who is also producing a description of their project on the computer. When they are asked why they have organised it this way, specifically why Mandy is looking up information in books, Deepti explains:

'Actually (.) when I look for information I prefer asking someone or reading a book. I also look on the Internet but I (.) I trust what I can find in a book and also what or hear from a person.'

Similarly, in the Danish NILSS project a group of three students is investigating possible topics for investigating space and while two of her group members, surf the Internet, Margit looks up information in a number of books. When she is asked about this she explains that she 'prefers it that way' and that she does not like reading information from a screen. From the conversations with the other students, it becomes clear that they find her stand peculiar and 'typical of Margit'.

Successful participation in digital classroom activities presupposes 'technological citizenship' [21]. However when this citizenship is imposed it may devalue other ways of being and learning, forcing students to take a position to defend themselves against stereotypical descriptions of what young people should be or need to become [5].

1.5 Discussion

This article is not intended to demonise the use of digital tools in science classrooms, far from it. Digital tools offer without doubt new opportunities for teachers and students to teach and learn, explore and communicate and relate to each other and one self. However digital tools also come with risks, old and new. The risk of oversimplifying young people's attraction to digital tools, may compromise other ways of being and seeing yourself. As Buckingham [5] puts it, it will become increasingly difficult to keep pace with the digital tools young people use and this gap can lead to oversimplifications of personal development.

Young people are entanglements of relations and interactions and form their subjectivity in a conscious way by way of anticipating and judging ideas [20]. But digital tools in science education are not value free and represent also agents of power. It seems therefore important to be aware of the intentions and agendas that are being promoted and carried forward in science classrooms, such as the place of opinions in science.

Digital tools have the potential to challenge traditional ways of being self in science and offer increased opportunities to renegotiate one's subjectivity with this discipline. The authentic instances that can shape how young people see themselves in science will benefit from critical approaches of utilising digital tools that facilitate such opportunities. Norman Ledermann [14] argues that unless young people understand the nature of science they will not gain any deep understanding in science. Taking this thought further implies also the need for understanding the range of tools that are used to access, utilise, produce or communicate in science classrooms, and how they shape young people's emergence, negotiation and struggle of different forms of subjectivities.

This article was concerned with values, norms and practices in science education and how the material arrangements specifically digital tools may contribute to fabricating young people's subjectivity. The most important point from this analysis is that digital technology, like any other educational tool carries intentional political and cultural agendas. Technology is not value free but rather adds complexity. It may highlight power relations, history or tradition. This is of significance in a subject like science and demands for careful considerations if young people's construction of self in science is taken seriously.

Acknowledgement The author wishes to thank the New Zealand Teaching and Learning Research Initiative who funded both the SCIAnTICT and the NILSS project. Thanks and acknowledgement goes also to the other researchers involved in the three projects as well as the teachers and students who participated and contributed to this research.

References

1. Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*(4), 417–436.
2. Anderson, J., Chiu, M.-H., & Yore, L. (2010). First cycle of PISA (2000–2006)—International perspectives on successes and challenges: Research and policy directions. *International Journal of Science and Mathematics Education, 8*(3), 373–388.
3. Basu, S. J., & Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. *Journal of Research in Science Teaching, 44*(3), 466–489.
4. Blackman, L., Cromby, J., Hook, D., Papadopoulos, D., & Walkerdine, V. (2008). Creating subjectivities. *Subjectivity, 22*(1), 1.
5. Buckingham, D. (2008). Introducing identity. *Youth, Identity, and Digital Media*, 1–24.
6. Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge, MA: Harvard University Press.
7. Foucault, M. (1982). The subject and power. *Critical Inquiry, 8*(4), 777–795.
8. Healy, L., & Powell, A. (2013). Understanding and overcoming "disadvantage" in learning mathematics. In M. A. Clements et al. (Eds.), *Third international handbook of mathematics education* (pp. 69–100). New York: Springer.
9. Hekman, S. (2009). We have never been postmodern: Latour, Foucault and the material of knowledge. *Contemporary Political Theory, 8*(4), 435–454.
10. OECD. (1989). *Education and the economy in a changing society*. Paris: OECD.
11. OECD. (2006). *Evolution of student interest in science and technology studies. Policy report*. Paris: OECD.
12. Ladson-Billings, G. (2006). From the achievement gap to the education debt: Understanding achievement in U.S. schools. *Educational Researcher, 35*(7), 3–12.
13. Latour, B. (1993). *We have never been modern*. Cambridge, MA: Harvard University Press.
14. Lederman, N. G. (1999). EJSE editorial: The state of science education: Subject matter without context. *Electronic Journal of Science Education, 3*(2).
15. Otrel-Cass, K., Cowie, B., & Khoo, E. (2011). *Augmenting primary teaching and learning science through ICT*. Wellington: Teaching and Learning Research Initiative.
16. Otrel-Cass, K., Khoo, E., & Cowie, B. (2014). Networked environments that create hybrid spaces for learning science. *E-Learning and Digital Media, 11*(1), 88–104.
17. Pyyhtinen, O., & Tamminen, S. (2011). We have never been only human: Foucault and Latour on the question of the anthropos. *Anthropological Theory, 11*(2), 135–152.
18. Rosa, H. (2013). *Social acceleration: A new theory of modernity*. New York: Columbia University Press.
19. Schreiner, C. (2006). *Exploring a ROSE garden. Norwegian youth's orientations towards science – Seen as signs of late modern identities*. Oslo: Department of Teacher Education and School Development, University of Oslo.
20. Sullivan, P. (2012). *Qualitative data analysis: Using a dialogic approach*. Los Angeles: SAGE Publications Ltd.
21. Svensson, M., Zetterqvist, A., & Ingerman, Å. (2012). On young people's experience of systems in technology. *Design & Technology Education, 17*(1).
22. Wertsch, J. (1998). *Mind as action*. New York: Oxford University Press.
23. Williams, J., Cowie, B., Khoo, E., Saunders, K., Taylor, S., & Otrel-Cass, K. (2013). *Networked inquiry learning in secondary science classrooms*. Wellington: New Zealand Council of Educational Research.

Chapter 2
Learning Science in a Collaborative and Technological Environment

Éric Durocher

2.1 Introduction

Since 2005, the new competency-based state curriculum in the province of Quebec, Canada, invites teachers to develop the ability of using information technology and communication (ICT) in all subjects. The ICT is also often considered a source of motivation and engagement [9, 12] as well as helping tools for students who are facing learning difficulties [11]. But this integration is difficult for most teachers [10]. This has led us, like many other educational institutions, to consider a different way to learn and to help students. This innovation report will present the rationale behind the creation of this very innovative learning environment and will explain, based on our experience and our observations, how it favors learning.

2.2 Why Adopt a Collaborative Learning Environment?

As a science teacher at a secondary High School in Québec, I attempted to integrate information technology and communications in one of my science classes to help a group of students facing very serious learning difficulties. I encountered many obstacles, technical difficulties and, most of all, pedagogical complications. In order for technological-based classrooms to be beneficial, it is not enough to simply add computers in a classroom and continue to carry out the same learning tasks as before

É. Durocher (✉)
Université du Québec à Montréal, Case postale 8888, succursale Centre-ville, Montréal, Québec, Canada, H3C 3P8

École Secondaire Dalbé-Viau, Commission scolaire Marguerite-Bourgeoys, 1100, bd. de la Côte-Vertu Saint-Laurent, Québec, Canada, H4L 4V1
e-mail: eric.durocher@csmb.qc.ca

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_2

[8]. Students are the first to let you know when things are not working well. That's what happened when I first asked my students to take class notes on their computer. I was typing the notes in front of the classroom and trying at the same time to teach the basics of the word processor, when I realized that half of my class was not typing. When I asked them why they were not taking notes, they said that I just might as well share my files at the end of the course. They were right. They were already used to share files and numeric data. I then realized that the benefits of a computer class probably were elsewhere, and that it probably would be better to seek a different way to teach with computers to really meet my goal of helping these students.

The integration of ICT implies a different type of teaching to allow students to learn efficiently and in order for the computer to provide a true advantage [13]. I undertook to assign some research projects and began to understand that my students had access to a phenomenal amount of information that was presented in a lot of different ways: texts, photos, animation, videos, newspapers, virtual museums. I noticed that they processed the explanations they contained at a very high speed and that everyone could find a suitable approach to learn from these resources. However, I began to have difficulty to keep my class quiet. My students were always discussing. It was obvious that I needed to find a way to prevent this "misbehavior". But then I observed that my students doing so because they felt the need to validate with their peers the understanding of what they had read. The group had started to build and rebuild their understanding. My presence in front of the class as an information transmitter was progressively less frequent. I often sat with my students to persuade them to dissect the information found and help them understand it. Students increasingly felt the need to validate and share their understanding.

These observations led me to focus on the various existing teaching methods. Collaborative learning had quickly established itself as a solution to facilitate the integration and learning using ICT. Collaborative learning helps students to solve problems or challenges by sharing and building together their comprehension over discussions and discoveries [14]. This way of learning relies on a communication and exchange of ideas, it then follows by a comparison of understandings and conceptions as well as cognitive conflict [3]. It is important to mention here that we made a distinction between collaboration and cooperation that are sometimes used as synonyms [5]. When we speak of cooperation, the teacher divides the work into sub-tasks that are performed individually and then assembled. While collaboration requires that team members work together throughout the task [5]. This educational approach, as mentioned by Beichner et al. [4], brings a better learning of physics and engagement in the tasks related to it. The combination of technology and collaborative learning is a necessity to confront the exponential growth of knowledge and with this new way students are learning and acquiring new knowledge. Digital tools provide flexibility in courses and facilitate collaboration [6]. Despite this, schools that are putting forward this kind of pedagogy remain rather rare. We tried to adapt the IT tool to traditional teaching methods with a lot of frustration associated with difficulties with classroom management, plagiarism, problem understanding information found on web, etc. Often singled out for its complexity and its inability to implement in schools, collaborative learning remains an uncommon practice in our educational settings. Nevertheless, the implementation of a collaborative learning environment and technology leads us to see the potential of such an approach in integrating technologies.

2.3 The Learning Environment

When a visitor enters in this classroom, he or she can immediately see students standing while writing on an interactive board, while others sit at their place listening to video documentaries on a computer or reading information found on the Internet, as well as others who are exchanging ideas and discussing their understandings. There are multiple and diverse resources as well as various ways students can accomplish the learning tasks.

For three years now, Dalbé-Viau High School designs and develops, improves and sustains such learning environments that are based on collaboration among high school students. Each of these classes contains six interactive whiteboards which face work islands of four or five students with a laptop for each (Fig. 2.1). These boards belong to students and are considered as a working and collaboration tool. The class is also equipped with Wi-Fi to allow students to move into their learning environment while ensuring they always have access to the Internet and to the school network. Along the same line, students in this class, unlike the rest of the school, have access to social networks, such as Google+, Facebook and Twitter; they also have access to video sharing sites such as YouTube. These platforms are accessible for students, with the help of the teacher, learning, sharing and working tools. The class also has a platform that allows students to create virtual classrooms which allows them to meet remotely and continue or complete the work initiated in class.

Fig. 2.1 One of the collaborative and technological environment

2.4 How Do We Learn in This Classroom?

Lecturing is not the main method of teaching in this class. Both the teacher and the students learn through problem solving, challenges and projects which arise in students an instinctive response often based on "unscientific-" or "mis-" conceptions already existing in their mind. They then confront the "unscientific" concept to other students, and the teacher can facilitate discussions and exchanges amongst the students. However, these preconceptions are not usually understood well enough so that students can hold whole conversations that might convince their colleagues that they were right. But these "constructions" can nevertheless be shaken a bit and doubt often begins to settle, in an early cognitive conflict forms [7]. This is when students usually leave in search of evidence to defend their ideas. The computer is then the perfect tool for this task. Unlike the textbook which often contains the answer in a beautiful red bold font, digital resources offer a much more challenging way to find answers and need to be analysed and validated. The computer also provides software and tools such as camera photos and videos that can be quickly and easily used to represent experimental results which can provide students the opportunity to analyse their results [4]. This search for meaning leads to successions of exchanges of information, different interpretations and contradictions that lead students to question their original conceptions and bring them to create a new common design or model. Of course, teaching plays a very important role in this reflective process and we observe, from the past three years, important aspects that we have to follow to generate learning.

2.4.1 Initial Mandate

The initial mandate that is given to students should be carefully designed so that they can achieve the desired goal or obtain quality cognitive conflicts and better understanding of the studied scientific concepts. To get there, a question, a challenge, a project to accomplish, a result of an experience or simply ask the class to bring the best possible evidence seem to be the best way to bring student to learn together. However, this starting element must be properly dosed so that it is not too easy or too difficult to manage. If it is too easy, students have all the same response, which will quickly end the trade and team interactions. If it is too complicated, the team faces demotivation and possibly accepts as true the first definitions found on the Web. It is possible to adjust this level of difficulty by giving some clues to the teams at certain strategic moments. Also, the initial mandate should not be too direct so that students can use the methods and resources that are favorable to them. It is appears very important that the initial mandate allows the team to validate its understanding of the concept, so that the work does not lead to the acquisition of misconceptions.

2.4.2 Pupils Should Be Able to Exercise Their Autonomy

The use of ICT in this pedagogical approach appears to be an important factor because it gives access to a wide variety of information and ways to learn. Students may consult videos, images, articles and research, and even use experiments to build their understanding. To keep the educational value of this research process, it should not be controlled too tightly by the teacher. He or she should not, for example, provide lists of websites or consider relevant digital resources containing the desired response. This is because the discovery of conflicting information on the Internet is an interesting and important source of cognitive conflict and educational discussions in teams. When digital resources are provided, the student quickly discovers the expected answers; the learning process is then somehow short-circuited because students are influenced by the given resource instead of discovering information on their own through free research and exchange. Therefore, students find information without necessarily having understood the information, processes and answers. It is nevertheless recommended that the teacher has some resources noted, in the event that a team is faced with a problem so strong that demotivation threatens.

It also appears benefit to allow students to move around in the environment, to be authorized to stand in order to use their interactive board properly, to use headphones for watching online videos and even give them the chance to perform experiments to confirm or deny their understandings.

2.4.3 The Importance of Guiding and Facilitating

To take full advantage of this kind of learning environment, the teacher has a very important role throughout the process. First of all, the teacher has to ensure that discussions are favored and that they actually take place. If every team member thinks the same way or if the discussion does not ignite, the teacher might sit with the team and question some students or ask them to vote so this can bring them to question their initial conceptions or question the understanding of another team member. When students are experiencing for the first time this learning approach, it is common that they are embarrassed to speak and are afraid of not having right answers. They often are used to give correct answers and are sometimes afraid of being wrong. The teacher needs to encourage students by explaining that, being wrong is alright and common, especially at the familiarization stages. Our experience showed that it can take as much as 3 months to achieve this kind of work culture.

Teacher must sometimes revive the discussion within teams. Indeed, it happens that all students end up with the same website that so often leads to the same "answers" and they get certain aspects of the original mandate. In these cases, they might not easily question their early understanding. Teachers must control this possibility and confront students' ideas with interventions that have the potential to bring doubt and to stimulate discussions. Teacher, however, do not have to be too active agents in such discussion. Depending on the richness of discussions, it is even sometimes better if they avoid participating altogether. But this happens to be difficult because teachers have the bad habit of providing answers to questions when these are asked by students. Learners should and can, with the computer, search for the answers themselves.

Teachers should also ensure that the learning process of the team does not lead to misconceptions. Indeed, some interpretations can lead or reinforce misconceptions among students. It is therefore important to have anticipated the most common misconceptions associated with the addressed topics in order to be in position to deal with them when they emerge. When teachers take the time to visit each team in their learning process, it is easier to see the emergence of such misconceptions and quickly challenge them by, for example showing a video on YouTube previously found for this occasion and generate cognitive conflicts, restart discussions and encourage research. After all, a teacher jobs is to guide students toward the desired conceptions. If a little wandering can prepare students' minds to recognize useful conceptions when they appear, too much could also bring demotivation and crucial loss of time.

2.5 The Benefits

After three years of implementation, we can clearly identify some benefits regarding this learning approach. Among them, we can evoke autonomy. Indeed, students quickly learn to efficiently use the tools that are at their disposal and understand that they can find, interpret and analyze the required information for their understanding. To this ability, we can add a high level of mobilization and rapidity to consider solutions to address problems or conflicts. These kinds of interaction seem to have important impacts on retention and achievement [2]. Another important benefit of the *PEAi* approach is that constructive doubt takes an important place in the classroom life. Students in this type of classroom must constantly analyze and question their understanding and their original comprehensions, which makes it easier to inhibit and address their misconceptions. It appears that *PAEi* has a positive effect on students' performance and brings a significant gain of motivation. This observation points in the same direction as those of Akinbobola [1], who suggested with convincing evidence that collaborative learning is the most effective learning strategies (compared with individual and competitive settings). This report of innovation also suggests that it is possible to create, using technology, a collaborative environment where students can develop their knowledge and scientific skills.

References

1. Akinbobola, A. O. (2009). Enhancing students' attitude towards Nigerian senior secondary school physics through the use of cooperative, competitive and individualistic learning strategies. *Australian Journal of Teacher Education, 34*(1), 1.
2. Astin, A. W. (1993). *What matters in college?: Four critical years revisited* (Vol. 1). San Francisco: Jossey-Bass.
3. Baudrit, A. (2007). *L'apprentissage collaboratif: plus qu'une méthode collective?* Bruxelles: De Boeck Université.
4. Beichner, R. J, Saul, J. M, Abbott, D. S., Morse, J., Deardorff, D., Allain, R. J, . . . Risley, J. S. (2007). The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project. *Research-Based Reform of University Physics, 1*(1), 2–39.
5. Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford: Elsevier.
6. Fourgous, J.-M. (2012). Apprendre autrement» à l'ère du numérique. Rapport de mission parlementaire.
7. Hake, R. R. (1992). Socratic pedagogy in the introductory physics laboratory. *The Physics Teacher, 30*, 546–552.
8. Hayes, D. N. A. (2007). ICT and learning: Lessons from Australian classrooms. *Computers & Education, 49*(2), 385–395.
9. Karsenti, T. (2003). Favoriser la motivation et la réussite en contexte scolaire: Les TIC feront-elles mouche. *Vie pédagogique, 127*, 27–32.
10. Karsenti, T., & Collin, S. (2013). Avantages et défis inhérents à l'usage des ordinateurs portables au primaire et au secondaire. *Éducation et francophonie, 41*(1).
11. Lagrange, J.-B. (2000). L'intégration d'instruments informatiques dans l'enseignement: une approche par les techniques. *Educational Studies in Mathematics, 43*(1), 1–30.
12. Matchinda, B. (2008). 14. Les TIC, l'apprentissage et la motivation des filles et des garçons au secondaire au Cameroun.
13. Moll, M. (1997). Information technology in the classroom: Pits and pendulum – A Poe-esian look at planning. *Education Canada, 37*(1), 6–9. 23.
14. Van Boxtel, C. (2000). *Collaborative concept learning*. Unpublished PhD dissertation, University of Twente, Enschede.

Chapter 3
Tracing Computer Assisted Assessment for Learning Capability in Greek Teachers

Zacharoula Smyrnaiou, Kathrin Otrel-Cass, Evangelia Petropoulou, and Eleni Spinou

3.1 Introduction

During the last decade within the context of educational reforms carried out in various countries around the world, there has been a tendency to focus on the outcomes from assessment practices as a key factor in shaping the quality of education. However, according to a critical consideration of the application of the instituted student assessment, assessment practices remain often traditional. This inconsistency of reform with regard to the application of the assessment for learning model has triggered our research.

In the context of this research, five universities from five countries are involved in the 'Tracing Assessment for learning Capability in Teachers' (TACT) project, aiming to investigate how student teachers develop and construct assessment literacy over the course of their teacher education programme and into the first 1/2 year of their classroom practice as in-service teachers. The shared research tool selected for this specific study was a questionnaire which constituted a translation of one applied in an earlier study in New Zealand in the 'Learning to become "assessment capable" teachers' project that was conducted across four universities in

Z. Smyrnaiou (✉)
University of Athens, National and Kapodistrian, Zografou, Greece
e-mail: zsmyrnaiou@ppp.uoa.gr

K. Otrel-Cass
Department for Learning and Philosophy, Aalborg University, Aalborg, Denmark
e-mail: cass@learning.aau.dk

E. Petropoulou • E. Spinou
Educational Technology Lab, School of Philosophy, Faculty of Philosophy, Education and Psychology, Department of Education, National Kapodistrian University of Athens, Room 545 and 540, University Campus, Ilisia, 15784 Athens, Greece
e-mail: liana.petropoulou@gmail.com; eleni_spinou@hotmail.com

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_3

New Zealand from 2010 to 2102 [14]. However, there was a need to make modifications to the questionnaire to accurately and precisely address and reflect the existing conditions of the Greek educational system. By the same token, the Greek research team has chosen to use a web-based questionnaire which additionally includes tools and questions concerning CAA. This decision was based on the fact that the use of ICT tools in education has increased in Greece since it has been identified as a key strategy with considerable benefits for the learning process. Thus, CAA appears to be an innovative and reliable form of assessment, enhancing the possibilities of validity, adjustment and continuous improvement of the assessment procedure.

This paper will discuss findings from the pilot phase of the Greek research, where student teachers, as well as in-service teachers, collaborated in the review and adaptation of the TACT questionnaire. Their insights provided us also with information which indicate that student teachers' beliefs about assessment remain close to the beliefs of students as recipients of assessment, whereas more experienced in-service teachers have managed to shift their perspective to the point of view of the educator who implements assessment in order to mediate learning successfully. The project also involves the close interaction between researchers, teacher training practitioners and their students to ensure that educational research is aligned with and aware of organizational practices and policies to build capacity within and across those organizations. The main objective of the project is the establishment of an informed community of professionals which will apply and inculcate into students an inquiry-based approach towards assessment with regard to the cognitive, social and pedagogical elements.

3.2 Rationale and Purpose of the Study

Students' assessment, as a mechanism for continuous monitoring, intervenes and dramatically affects the formation of effective pedagogical practices, as well as the improvement of students' learning level [5]. As a result, there has surfaced a need for maintaining a focus on the effective attribution and mechanisms of formative assessment, as well as the crucial role of classroom teacher assessment in leveraging its potential. However, although research studies have put an emphasis on the necessity and the purposeful requirement for teachers to be assessment literate [3, 19, 31, 34], they appear to have limited knowledge and academic training in the possession and application of effective assessment practices and to possess only a limited repertoire of assessment methods and techniques, that are orientated mainly towards summative assessment [25, 30, 33]. In addition, the channelling of assessment in classrooms seems to be mostly dictated by nationally standardised objectives, leaving no room for professional development or use of individual, student specific needs to progress their learning.

In Greece, during 2003–2004, when the development of new curriculums, based on relevant regulations, occurred, a model of formative assessment was proposed that highlighted and projected the need for learning and instruction to be assessment-guided, in order to engage students in meaningful learning and provide them with valid and transparent indicators of what they can readily use, in order to evaluate their own conceptual knowledge in relation to their acquired skills [29, 30]. The National Policy declared the modernization of students' assessment with guidelines that institutionalized the connection of assessment practices' application with all teaching processes.

However, according to a critical consideration of the application of the instituted assessment policy, teachers' assessment practices remain traditional [17, 21, 30], despite teachers' declared appreciation of formative assessment in the educational process [36]. This is mainly due to a lack of professional training or expertise that would orientate teacher practices to track an individual student's position on a cognitive evolution path [12, 18]. This project seeks to contribute to our understanding of the development of teacher assessment capability, through a focus on the nature of assessment education, in initial teacher education programs and their impacts in five countries (United States, New Zealand, Denmark, Hong Kong, Greece and Canada). The intention is to learn about assessment education, through the sharing and analysis of current practice and its impact, involving the collaboration between university researchers, teacher educators and student teachers.

3.3 Related Work

3.3.1 The Necessity for Incorporating Technology in the Assessment Process

A real challenge in the learning process is connecting individual student data to the appropriate instructional techniques and methods, as well as resources. The introduction and incorporation of ICT-based teaching, in every aspect of the learning process, has triggered the appearance of computer-based techniques in the assessment process as well. Besides, it would be really inconsistent to support and foster ICT-based teaching but evaluate students' work by persisting in the use of traditional, on paper techniques or old-fashioned pedagogies [32], which are mainly based on students' counterproductive classifications according to grades [11]. Computer assisted assessment appears to be an appropriate and effective instructional method of student assessment since it has the potential to elaborate and combine a huge number of information gathered from multiple entries during the learning process and consider both the student's output and the 'event stream' [4, 6, 26]. Since, according to modern pedagogical theories, our main concern is to prioritise supporting learning over measuring learning, formative assessment finds a stable ground for establishment in computer assisted assessment, which combines a wide variety of formats for question design, such as computer-based simulations, electronic grading, item banks, real-time student interactive response, computer-adapted testing, etc.

First of all, CAA facilitates computer adaptive testing, which refers to an automatic variation of the test content, as it progresses, in order to effectively address students' weaknesses, as they emerge during the test. As a result, we are equiped with tests that are tailored to match students' abilities and therefore we are able to purposefully address each student's needs. Moreover, the necessary and valuable quality of feedback provision [37] is also facilitated by CAA due to its immediacy in delivering well structured high quality information [28]. CAA gives us the opportunity to record pupils' interactions and analyse them at the same time, providing a richer understanding of learning. In addition, students are given the ability to engage in self-evaluation or peer–assessment processes [2, 7, 15], which entail immediate response and a sense of responsibility for self-improvement.

However, the validity and reliability of CAA relies on the the creation of appropriate question banks, which are relevant to the level of challenge aspired to and effectively address the learning objectives in an allignment with the targeted curriculum [22, 35]. A basic advantage of appropriate question banks is their ability to provide a wider coverage of the cognitive content, in comparison to essay type questions. CAA also enables the construction of assessments using multimedia, which entails pupils' interaction in different ways and in terms of various skills [1, 23]. For example, computer-based simulations constitute a hand-on assessment that necessitates application of acquired techniques and skills, rather than a sterile memorisation of theory. In addition, question banks allow reusability or even repetition – by presenting, each time, different variations of the same question content – which ensures major time savings. This aim favours the creation of electronic communities of teachers around specific syllabuses, which entails a creative and productive cooperation among professionals, towards the emergence of the best possible outcome. However, in terms of item banks' sustainability and appropriateness, it is important to invest a lot of time and attention in their creation, bearing in mind, not only, the cognitive context under negotiation, but also the level of skills which are to be assessed (lower order/higher order). Finally, the objectivity of testing is ensured with the quality control based on the analysis of the question – in terms of its classification in the question bank – as well as the elimination of lucky guessing, by applying the corrective scoring technique [24].

3.3.2 Configuration of an Inquiry–Based Model Approach towards Assessment

The application of the assessment process -in a well-structured and supported frame- necessitates an inquiry-based approach for the establishment of specific assessment criteria and guidelines [13]. The inquiry-based model of assessment, which refers to the process through which assessment content is addressed, requires an in-depth information processing by teachers, as well as students, when peer-assessment is applied.

The inquiry-based model approach towards assessment builds on three basic elements: cognitive, social and pedagogical [10, 20].

While examining the purpose, practice, principle and policy aspects of assessment, as well as their extensions in terms of CAA, we refer to the three inquiry elements (cognitive, social, pedagogical) as a guidance in the design of a thorough and inclusive research context, but also as a sound basis of reference and facilitator in the search of scientifically relevant indicators. These indicators address the analysis of the definition of the main theoretical axes, as informed by relevant literature and are grouped into categories in order to explicitly indicate the context of the element they address. Table 3.1 illustrates the way the three essential elements are processed and the context in which they are used in our inquiry-based assessment research.

The term cognitive is used, in this context, to address the issue of meaning construction [10], through a sustained interaction among a number of assessment criteria and objectives. The design of an assessment process necessitates a thorough selection of multi-faceted elements such as content knowledge, application of appropriate skills, inclusion of motivational and challenging elements, consistency with students' needs, etc.; all of which require application of higher order cognitive skills and critical thinking. The term social refers to the collaborative constructivist perspective of inquiry [8, 9, 27] that should be applied on the assessment process. The aspect of social element addresses first of all the teacher-student interaction and collaboration in mutually formulating the assessment criteria and objectives that will inform the learning process, but also refers to all stakeholders involved (national educational policy, curriculum consistency, school unit administration, parents, Board of Trustees, local community) who also inform the criteria and objectives. This collaborative inquiry approach results into a preservation of equilibrium among

Table 3.1 Assessment inquiry coding template

Elements	Categories	Indicators (examples only)
Cognitive	Purpose/Purpose of CAA	Summative assessment
		Formative assessment
		Conceptual development
		Assessment based on frequency, focus, stage, quality, differentiation
Social	Principle/Principles of CAA	Reliability
		Validity
		Transparency/Objectivity
		Internal consistency
	Policy/Policy of CAA	Macro level
		Meso level
		Micro level
Pedagogical	Practice/Practice of CAA	Design and production agent
		Teachers' personal resources
		Student involvement

all social factors and helps in the shaping of social acceptable parameters to be considered in assessment. Finally, the pedagogical element of assessment refers to the channelling of the assessment process, as dictated by modern pedagogical theories, which evolve around the self-regulating student profile [16]. Rather than imposing assessment rubrics attached to learning outcomes, it is more efficient to engage students into a shared experience, whose main aim is the construction of meaning and awareness of metacognitive mechanisms, that inform and improve their learning [10]. All three elements examined and perceived in the context of the inquiry-based model approach will help us to establish a common framework of the assessment conditions and criteria, as a grounded reference, for the design and effective application of the assessment process.

In this work, we also seek to use the gained knowledge and expertise deriving from the research project in order to inform the design of CAA tools. By systematically and responsibly informing the computerised media, in terms of assessment delivery, we manage to extend and upgrade their potentials, in terms of cognitive, social and pedagogical efficiency.

3.4 Study Design and Methodology

The TACT study aims to investigate how student teachers develop and construct assessment literacy over the course of their teacher education programme and into the first 1/2 year of their classroom practice, as in-service teachers. Our specific purpose is to understand the nature of the programmes used by different countries to foster student-teacher assessment literacy and to trace changes in student-teacher literacy over time. The survey is critical in obtaining data that could be used for the improvement of the student teachers' training, in terms of assessment practice, purpose, principles and policy, as crucial aspects that enable a holistic overview of the assessment application effect.

Upon our research target, we have agreed on the formation of a questionnaire due to be addressed to students, in order to evaluate their primary beliefs about assessment. The selection of the specific research tool was a common decision, after examining its appropriateness for the production of reliable findings and its efficacy in accommodating the different settings of the educational policies of each involved country, in order to enable us in the identification of commonalities, on the basis of shared cross-cultural values, paradigms or discourses.

In the pilot phase of the research study conducted in Greece, there were eight participants: four pertaining to the student-teacher category (in their 2nd year of studies in the Physics department) and another four pertaining to the more experienced teacher category (in their 1st year of their in-service teacher appointment as teachers of physics). The questionnaires were web-based and therefore had to be completed online.

3.4.1 Description of the Research Tool

A belief about assessment questionnaire was developed for this research, as adapted and translated by the relevant one applied at the New Zealand's project. The present questionnaire was designed around four themes: purposes, practices, policies and principles in order to enable us to obtain a holistic overview of the assessment application effects. By addressing these issues, our main objective was to define the student teachers' initial beliefs towards assessment and to examine whether they are subject to change during their academic courses.

The original New Zealand survey tool consisted of 56 items. The modified form of the survey instrument, used in this research, has 92 items, structured into six sections: *personal information*, *teaching intervention based on research protocol*, *personal experiences regarding assessment, intentions regarding assessment*, *beliefs about assessment* and *beliefs about computer assisted assessment.* The questions are presented in multiple forms, including: open-ended questions, order ranking, multiple choice, grading and likert questions.

3.5 Analysis and Results

The comparative analysis, from the data collected from the two focus groups (2nd year student teachers and 1st year in-service teachers), enabled us to track the teachers' transitional phase, in terms of assessment perception and intention of application. In the context of the cognitive element, analysing the participants' perceived purpose of the assessment process, a significant differentiation was registered between the two focus groups. Although in terms of the summative indicator (assessment of learning), there was a total convergence of views, with assessment defined as a process to judge students' performance on the basis of certain goals, standards or criteria, there was a considerable differentiation in terms of the formative indicator (assessment for learning), with 100 % of in-service teachers treating assessment as a qualitative feedback in order to respond to student learning, with an aim of enhancing it by modifying their teaching to improve student attainment, whereas only 25 % of student teachers seem to share this assessment approach. Considerable differentiation was also registered for the conceptual development and the five dimensional aspect of assessment indicators, with 100 % of in-service teachers attributing cognitive qualities as an outcome of the assessment process, designed on a basis of equal importance to the frequency, focus, stage, quality and differentiation aspects, in contrast to only 25 % of student teachers sharing this aspect. However, it is of crucial importance that the discrepancy between the two focus groups is eliminated when the aspect of the purpose of CAA is examined. Both groups, on a percentage of 100 %, adopt a more holistic and multi-dimensional assessment approach, with the conduction of assessment via ICT tools, in all aspects of the assessment process, including its summative and formative channelling, as well as its cognitive impact and pedagogical applicability.

In the context of the social element, both focus groups (100 %) share the same opinion on the aspect of principles in terms of the reliability, validity, objectivity and internal consistency indicators, signaling this way the importance of inclusion and ensuring of such criteria in the assessment process. However, both groups, by the same percentage (50 %), express their disbelief and concern on the appearance of such principles in the case of standardized tests, considering this way the assessment in classroom to be a more reliable process. Again, when the principles of CAA were examined, there was a total convergence of views between the two groups (100 %), which expressed their reliance on the ICT tools for the conduction of reliable and valid assessment procedures. In the same social context, the policy aspect of assessment was examined, divided into three fundamental and all-inclusive levels: macro, meso and micro level. In the case of the macro level, all participants in the questionnaire (100 %) shared the same opinion, in terms of the necessity for a societal approach of assessment culture, including the educational policy, the impact of governmental or quasi-governmental agencies, the awareness and maintenance of national and worldwide policies supporting the importance of curriculum awareness, as well as perceiving assessment as a means to trigger the evolvement of curricula. However, there was a differentiation between the two focus groups in terms of the meso level aspect, with a 75 % of the in-service teacher group being against the connection or interference of the school unit administration with the assessment process, whereas all the 2nd year students (100 %) supported the idea of the school administration monitoring and registering all assessment outcomes, both standardised tests and classroom assessments. Additionally, all participants supported the idea of communicating the assessment results to children's guardians, as a means to inform them on their progress. As far as the micro level aspect of assessment is concerned, both focus groups support the teacher-student interaction and collaboration in mutually formulating the assessment criteria and objectives, that will inform the learning process. By examining the aspect of the policy of CAA, both groups agree on the efficiency of the application of computer technologies to the assessment process, as a crucial parameter and means that sets a grounded base for each level (macro, meso, micro) and as a facilitator for the communication and interconnection among the levels.

Finally, in the context of the pedagogical element, although both groups support the need for a three-axis establishment in the design and production of assessment – including the formal standardised assessment, the informal classroom assessment designed by teachers themselves and the student essential and direct involvement in setting the assessment rubrics – a high percentage of in-service teachers (75 %) seem to be in favour of diminishing the impact factor of the standardised tests, in contrast to the majority of the 2nd year students (100 %), who seem to rely heavily on the conduction of formal assessment processes. In addition, there is a significant differentiation between the two focus groups on the significance of the teachers' personal resources in the application of assessment. Only 25 % of the student teachers seem to acknowledge the teachers' pedagogical content knowledge in assessment design, as well as the importance of teachers' awareness of the targeted group, in contrast to the majority of the in-service teachers focus group. Furthermore, 75 % of the student teachers group perceive teachers' personal experience as a facilitating or hindering lens in assessment practice, with only 25 % of in-service teachers sharing this opinion. However, all participants in the questionnaire expressed their agreement on the importance and necessity for teachers' adoption of modern pedagogical theories, including ICT assessment and new updated ways for monitoring and communicating the assessment results. The tendency towards the adoption of ICT assessment was also examined in the practice of CAA aspect of the assessment process. It was a common ground for both groups, by a percentage of 100 %, that assessment via computer allows for student involvement, in terms of self-assessment and peer evaluation, enabling them to engage in critical reflection, evaluation and analysis.

3.6 Conclusions and Future work

The theoretical framework, adopted for this pilot study, enabled us to design a questionnaire that examines the assessment process, through an Inquiry-based approach, for the establishment of specific assessment criteria and guidelines. First of all, this pilot research study was successful in enabling us to confirm the efficiency and reliability of the questionnaire. In addition, two crucial themes emerged from the analysis of the gathered data. First of all, the differentiation among the two focus groups, mainly in the cognitive and pedagogical element of the assessment process, marks the transition phase that student teachers undergo during their pedagogical academic courses and the impact of this pedagogical informed instruction in the shaping and adoption of a more grounded assessment approach. The second issue that was raised is the common view of the two focus groups in terms of the efficiency of the CAA application. This tendency strengthens the conduction of the assessment process via ICT tools and denotes the necessity of their inclusion in the courses addressed to student teachers.

However, we must first proceed with our final research, that will track the transition phase of a larger group of student teachers from the first years of their studies, until their in-service appointment, before we are in a position to draw any grounded conclusions.

Acknowledgements 'Tracing Assessment for learning Capability in Teachers' (TACT) project.

References

1. Ashton, H. S., & Beevers, C. (2002, July 9–10). Extending the flexibility in an existing on-line assessment system. In *Proceedings of the 6th annual CAA conference*, Loughborough University, Loughborough, UK, pp. 3–16.

2. Boston, C. (2002). The concept of formative assessment. [Electronic Version]. *Practical Assessment, Research & Evaluation*, http://PAREonline.net/getvn.asp?v=8&n=9. Accessed 25 Feb 2014.
3. Broadfoot, P., & Black, P. (2004). Redefining assessment? The first ten years of assessment in education. *Assessment in Education, 11*(1), 7–27.
4. Bull, J., & McKenna, C. (2003). *Blueprint for computer-assisted assessment*. London: RoutledgeFlamer.
5. Chappuis, S., Chappuis, J., & Stiggins, R. (2009). Supporting teacher learning teams. *Educational Leadership, 66*(5), 56–60.
6. Conole, G., & Warburton, B. (2005). A review of computer-assisted assessment. ALT-J. *Research in Learning Technology, 13*(1), 17–31.
7. Davies, P. (2001). Computer aided assessment must be more than multiple choice tests for it to be academically credible. In *Fifth annual computer assisted assessment conference*, Loughborough.
8. Earl, L., & Hannay, L. (2011). Educators as knowledge leaders. In J. Robertson & H. Timperley (Eds.), *Leadership and learning*. Thousand Oaks: Sage Publishing.
9. Garrison, D. R., Anderson, T., & Archer, W. (2000). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education, 2*(2–3), 87–105.
10. Garrison, D. R., & Archer, W. (2000). *A transactional perspective on teaching and learning: A framework for adult and higher education*. Oxford: Pergamon.
11. Gipps, C. V. (2005). What is the role for ICT-based assessment in universities? *Studies in Higher Education, 30*(2), 171–180.
12. Halloun, I. A. (2007). Model-centered, assessment-guided learning and instruction in science. In *Proceedings of the 5th Pan-Hellenic conference 'Science Teaching and New Technologies in Education'*, 5(A) 2007.
13. Hannay, L., Wideman, R., & Seller, W. (2010). *Professional learning to reshape teaching*. Toronto: Elementary Teachers Federation of Ontario (ETFO).
14. Hill, M. F., Smith, L. F, Cowie, B., Gilmore, A., & Gunn, A. (2013). *Preparing initial primary and early childhood teacher education students to use assessment*. http://www.tlri.org.nz/sites/default/files/projects/Hill_Final%20Summary%20Report_signed%20off.pdf. Accessed 25 Feb 2014.
15. Jenkins, M. (2004). Unfulfilled Promise: Formative: Assessment using computer-aided assessment. *Learning and Teaching in Higher Education, 1*(1), 67–80.
16. Johnson, D., & Kress, G. (2003). Globalisation, literacy and society: Redesigning pedagogy and assessment. *Assessment in Education: Principles Policy and Practice, 10*(1), 5–14.
17. Kassotakis, M. (2003). *Assessment of students' performance*. Athens: Grigori (The original text is written in Greek).
18. Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*, 254–284.
19. Kyriakides, L. (2005). Extending the comprehensive model of educational effectiveness by an empirical investigation. *School Effectiveness and School Improvement, 16*(2), 103–152.
20. Lipman, M. (1991). *Thinking in education*. Cambridge: Cambridge University Press.
21. Mavromatis, I., Zouganeli, A., Kafka, D., & Stergiou, P. (2007). Student's assessment. *Review of Educational Issues, 13*, 84–98. (The original text is written in Greek)
22. McAlpine, M. (2002). Design requirements of a data bank. *Bluepaper Number 3, CAA Centre*, University of Luton. http://www.caacentre.ac.uk. Accessed 25 Feb 2014.
23. McGuire, G. R., Youngson, M. A., & Korabinski, A. A. (2002, July 9–10). Partial credit in mathematics exams – A comparison of traditional and CAA exams. In *Proceedings of the 6th international conference on computer-assisted assessment*, Loughborough University, Loughborough, UK, 223–230.

24. McKendree, J. (2002). *Negative marking & gender bias. Computer assisted assessment centre resources*. York: The Higher Education Academy. http://www.caacentre.ac.uk/resources/faqs/negative_marking1.shtml. Accessed 25 Feb 2014.
25. Mertler, C. A. (2004). Secondary teachers' assessment literacy: Does classroom experience make a difference? *American Secondary Education, 33*(1), 49–64.
26. Miller, T. (2009). Formative computer-based assessment in higher education: The effectiveness of feedback in supporting student learning. *Assessment and Evaluation in Higher Education, 34*(2), 181–192.
27. Moore, A. (2004). *The good teacher: Dominant discourses in teaching and teacher education*. New York: RoutledgeFalmer.
28. Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education, 31*(2), 199–218.
29. Pedagogical Institution. (2004). *Guidance for the implementation of the new assessment measures in primary and secondary education*. Athens: Pedagogical Institution. (The original text is written in Greek).
30. Pedagogical Institution. (2008). Quality in education. In *Evaluation of qualitative characteristics in the primary and secondary educational system*. Athens: Pedagogical Institution. (The original text is written in Greek).
31. Popham, W. J. (2006, September 15). *Defining and enhancing formative assessment*. University of California, Los Angeles, AfL Assessment for learning.
32. Raikes, N., & Harding, R. (2003). The horseless carriage stage: Replacing conventional measures'. *Assessment in Education, 10*(3), 267–277.
33. Stiggins, R. J. (2002). Assessment crisis: The absence of assessment FOR learning. *Phi Delta Kappan, 83*(10), 758–765.
34. Volante, L., & Fazio, X. (2007). Exploring teacher candidates' assessment literacy: Implications for teacher education reform and professional development. *Canadian Journal of Education, 30*(3), 749–770.
35. Wainer, H. (2000). *Computerised adaptive testing: A primer*. Mahwah: Lawrence Erblaum Associates.
36. Xirafidou, E. (2012). *Teaching adequacy of teachers in using effective forms of student assessment in Mathematics*. Thesis. (The original text is written in Greek)
37. Yorke, M. (2003). Formative assessment in higher education: Moves towards theory and the enhancement of pedagogic practice. *Higher Education, 45*(4), 477.

Chapter 4
Brain Activity and Visual Scientific Content: A Study on Earthquake Precaution

Georgios K. Zacharis, Angeliki Tsiara, Panagiota Chalki, Ioannis Vrellis, and Tassos A. Mikropoulos

4.1 Introduction

In the last two decades, a new field in educational research, that of educational neuroscience, emerges [13, 14]. According to educational neuroscience, under a biological basis and as a renovation of cognitive science in education, learning is defined as the process of "making neuronal connections in response to external environmental stimuli" [9, 20]. Recently, neurophysiological data have shed light on basic aspects of Science, Technology, Engineering and Mathematics (STEM) learning [17]. Neuroimaging techniques, such as Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI), have shown that visualisations supporting visual perception and imagery activate the two thirds of the brain [21]. Regarding virtual environments, fMRI measures have shown increased brain activity in both auditory and visual sensory cortices and reported that auditory cues increase activation in the hippocampus, a brain region associated with learning and memory [2].

Science education involves, among others, perception and orientation, visual and spatial perception, attentional demands, selection of objects and features, understanding of abstract concepts and models, spatial reflection of emotional and cognitive processes, information organization and processing, knowledge construction, metacognitive abilities and different cognitive styles [23]. These cognitive processes can be detected through neuroimaging techniques and contribute to a better understanding of the environmental stimuli used in science education. More effective learning environments could be designed and learning processes could be explained.

G.K. Zacharis (✉) • A. Tsiara • P. Chalki • I. Vrellis • T.A. Mikropoulos
The Educational Approaches to Virtual Reality Technologies Laboratory,
The University of Ioannina, Epirus, Greece
e-mail: gzacharis@uoi.gr; atsiara@cc.uoi.gr; pahalki@gmail.com; ivrellis@uoi.gr; amikrop@uoi.gr

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_4

As far as it concerns electric brain function, theta activity (θ, 4–7 Hz) is an indication of cognitive processing and "emotional stress" during task performance [16, 30]. The decrease of theta while solving problems is connected with incorrect answers [16]. Theta activity diffused in the scalp associates with reduced alertness and poorly information processing. "Anterior midline θ", is associated with selective attention, mental effort and increased processing complexity of the stimuli [26]. Theta activity is not strictly related to the amount of information that must be processed, but with the extent of processing that is required by a subject [24]. Theta activity in frontal and frontal midline regions indicates that information processing occurred [3]. Strong theta signals in the occipital lobes indicate visuospatial processes [31].

Alpha (α, 8–12 Hz) is the most extensively frequency band or rhythm studied. It appears during wakefulness in posterior regions of the scalp and is generally higher in the occipital lobes. Alpha activity is high in primary visual cortex when the subject's eyes are closed or the subject is in a relaxed state and reduces when eyes are open to a visual stimulus. Alpha activity in parieto-occipital areas correlates with attention [7, 28]. Changes in alpha power can determine whether a stimulus can be consciously detected [25]. The increased alpha activity has been proposed for predicting visual perceptual performance [5, 22, 29]. In general, an increase of alpha activity correlates with relaxation in most brain functions, while alpha decrease is an indication of wakefulness.

Alpha frequency band is divided into two sub-regions, the "lower alpha, α-1" (8–10 Hz) and "upper alpha, α-2" (11–13 Hz). This separation is made on the basis of the different behavior of these sub-regions in various cognitive functions. Lower alpha activity correlates with the encoding of the stimulus, while upper alpha correlates with cognitive processing and the mechanisms of cognitive effort [6]. Jaušovec & Jaušovec correlate lower alpha activity with semantic memory functions, while upper alpha mainly with attention [15].

Disaster education, involving earthquake precaution, is a new field in education research [27]. Cognitive processes, such as visual and spatial perception, attentional demands, selection of objects and features, are important in disaster preparedness. Students have to be aware of the correct actions in case of an earthquake. Brain activity can be used as a corroborative technique for the estimation of students' choices and decisions in case of a disaster.

This work presents the first neurophysiological results of students interacting with affective visual stimuli in a digital learning environment concerning earthquake precaution measures. Digital electroencephalography (EEG) was used to measure electric brain activity, as a high temporal resolution technique.

The study provides baseline measurements, to be later compared with specific learning task performances and show "the potential of the neurosciences to inform the design and use of technology enhanced learning" [14].

4.2 Materials and Methods

4.2.1 Research Objectives

The aim of the present study was the comparative study of electric brain activity of women during identifying ten different images depicting non-useful items (NUI) and useful items (UI) that they have to bring with them in the earthquake survival kit. The research objectives were to explore possible differences in brain activity connected with visual awareness and mental effort between the useful and non-useful items.

4.2.2 Sample

The sample was fifteen (15) students – future teachers, all female volunteers of ages 19–22 years (Mean = 19.61, SD = 1.51). The participants were only women in order to avoid possible different brain activity because of gender differences, as for example, the stronger sensorimotor integration in females [19].

All participants had normal vision, were right–handed native Greek speakers, without certain diagnosed learning difficulties or mental disease. None of the participants received any medication or substances that affected the operation of the nervous system and they had not consumed quantities of caffeine or alcohol in the last 24 h before the experiment. The alpha rhythm of all the participants was checked and found to be normal (8–12 Hz, 10 Hz peak). The study conforms to the code of ethics of the University of Ioannina.

4.2.3 Environments and Procedure

The participants were asked to identify ten different images depicting non-useful (not necessary) and useful (necessary) objects that they have to bring in their earthquake survival kit. These ten images depicting both useful items (UI) and non-useful items (NUI) in case of an earthquake were presented to each subject. The five useful items were a cereal bar, a flashlight, a pocketknife, a bottle of water and a whistle (Fig. 4.1). The non-useful items were an ice cream, a hamburger, a laptop, a bottle of milk and a tool kit (Fig. 4.2).

Each participant was comfortably seated at eye level and 100 cm away from α 17” TFT monitor, passively observing the displayed images (Fig. 4.3).

A recommendation was made to the participants in order to avoid unnecessary movements that could cause artefacts during the EEG recordings. In the beginning of the experiment, each participant had a few minutes to adapt to the specific conditions, to relax and reduce the movements of their eyes.

Fig. 4.1 The useful items (UI)

Fig. 4.2 The non-useful items (NUI)

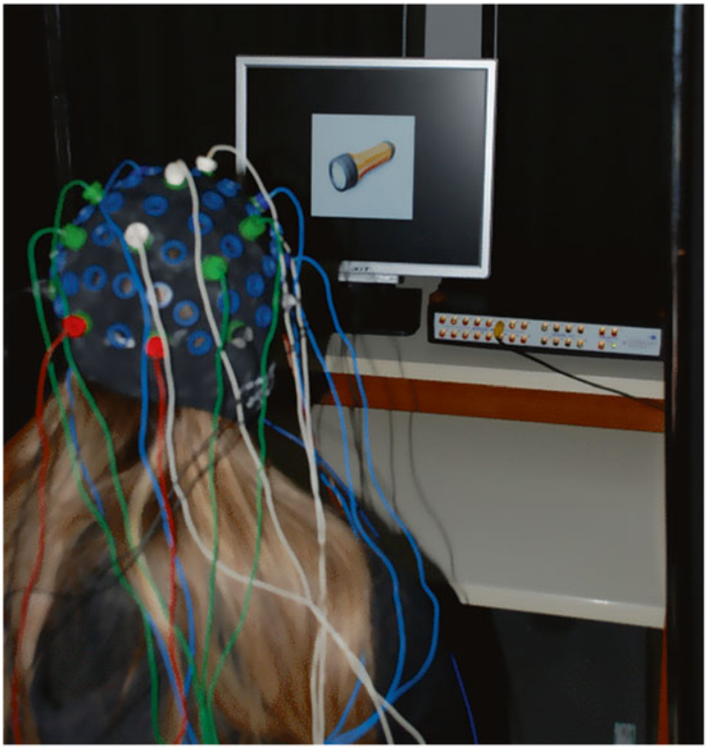


Fig. 4.3 A student observing a useful item

Before the EEG recording, the researchers gave a briefing to each participant about earthquakes and the relevant precaution measures. At next, the participant was familiarized with the UI and NUI objects. After that, the participant closed their eyes and stayed relaxed for 2 min. When they opened their eyes, the images (useful and non-useful) under study were randomly displayed. The participant was asked to open and close their eyes in certain intervals in order to minimize the artefacts during the EEG recording. The process included 30 repetitions of EEG recordings. After the completion of this stage, the participant closed their eyes and stayed relaxed for a few minutes.

4.2.4 Experimental Setup

EEG was recorded using a g.tec 36 channel amplifier with 256Hz sampling rate. The digital EEG data acquisition system had a 1–48 Hz band pass filter. EEG activity was monitored from 19 Ag/AgCl electrodes using an electrode cap with a standard 10–20 International Electrode Placement System layout. Raw EEG data was recorded from Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3 Pz, P4, T6, O1 and O2. All leads were referenced to linked ear lobe and a ground electrode was applied to the forehead. Horizontal and vertical eye movements were recorded simultaneously using four electrodes round the eyes. The electrodes impedance was kept below 5KΩ.

After removing eye movement and other artefacts, single trials were averaged per UI and NUI and subject. Moreover, the grand mean for each group of objects across all subjects was calculated. A Fast Fourier Transform was applied to the raw EEG data. Theta (θ, 4–7Hz), lower alpha (α-1, 8–10 Hz), upper alpha (α-2, 11–12 Hz) and total alpha (α, 8–12 Hz) frequency bands were studied within fronto-parietal (Fp1, Fp2), parietal (P3, Pz, P4) and occipital (O1, O2) areas. The processing and analysis of the signals were performed by using the gBSanalyze and Matlab software packages.

The signal comparisons between the useful and non-useful images and their representations on the scalp were performed by using the EEGproccessing software application, developed in our lab.

4.3 Results

Figure 4.4 shows the normalized brain maps for the useful (UI) and non-useful items (NUI) for each one of the frequency bands under study.

Theta activity appears in both UI and NUI, but in different cerebral areas. In UI it appears in the left fronto-temporal areas, left parietal (P3) and right occipital electrode positions (O2). Theta activity in NUI appears mostly in the pre-frontal areas. The strong theta signals in the occipital lobes for UI indicate the visuospatial pro-

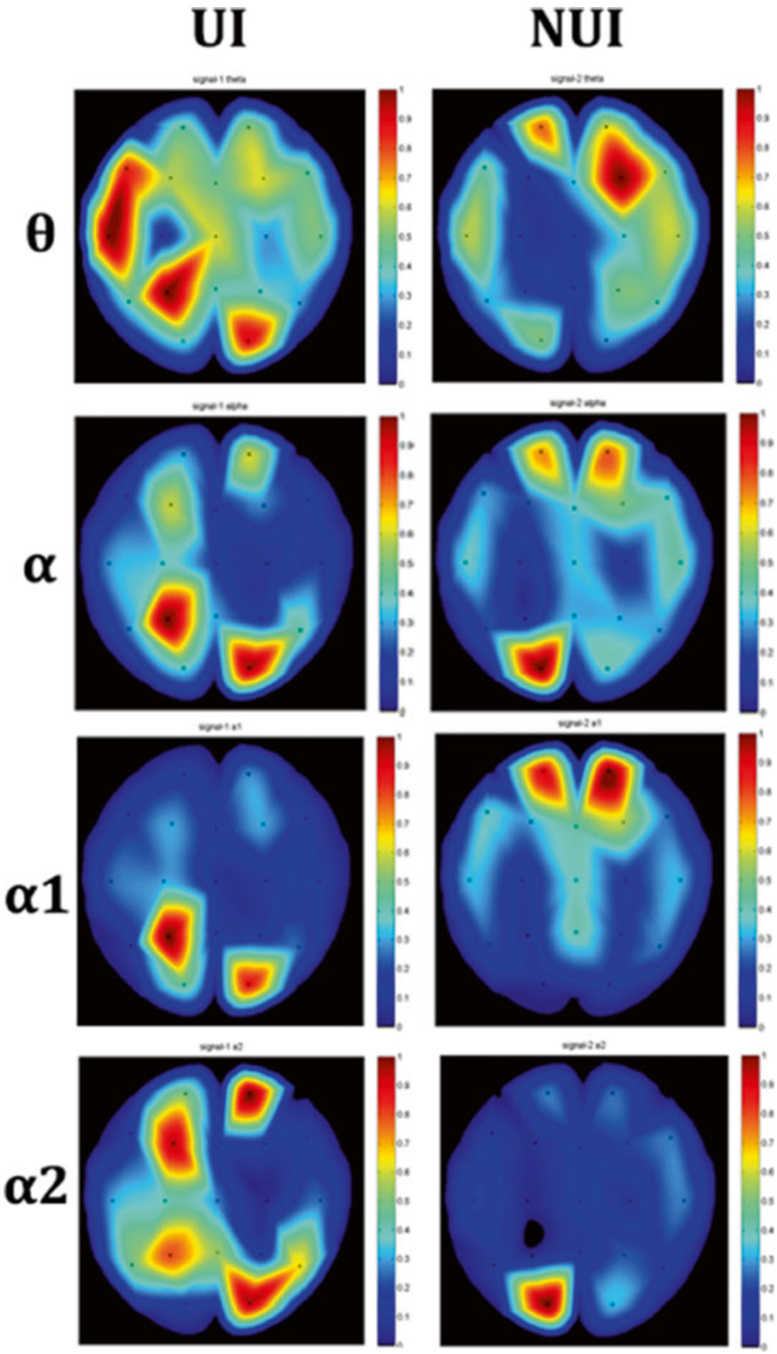


Fig. 4.4 Power and spectral distribution for the useful (*left column*) and non-useful (*right column*) items

cess. The temporal activity in both groups of items indicates attention processing [1] and retrieval of information from long-term memory [11]. The statistically significant (Table 4.1) higher power of theta activity at the pre-frontal area (Fp1, Fp2) for the NUI shows that they required a greater attention as far as it regards the visuospatial component of the task [12]. It is also an indication that information processing indeed occurred [24].

Total alpha activity is located in both UI and NUI in pre-frontal and occipital areas. Lower alpha activity in UI appears mostly in the occipital lobe, while in NUI it appears in the pre-frontal lobe. Upper alpha activity shows the same behavior for UI as total alpha activity. For NUI, it is located in the left occipital lobe (O1).

Table 4.1 shows the statistically significant power differences between the useful and non-useful items with a significance threshold of 0.05. UI means statistically higher for useful items while NUI for non-useful items

As it is shown in Table 4.1, there are statistical differences in theta activity in the left and middle (P3 and Pz) parietal electrode positions for UI, while in the right position P4 appears statistical difference for NUI. NUI signals are statistically higher in the left occipital lobe (electrode O1), while UI in the right occipital lobe (O2). The strong theta activity in the occipital lobes indicates the visuospatial processes for both groups of images.

Lower alpha activity appears statistically higher for UI in left pre-fronto-parietal area (Fp1) contrary to the right pre-frontal area (Fp2) that appears statistically higher for NUI. Upper alpha activity appears the same as lower alpha. According to Klimesch, statistically higher upper alpha activity in right pre-frontal and frontal areas implies primary visual processing and activates higher brain functions such as memory [18]. Total alpha activity appears statistically higher only in the right pre-frontal area (Fp2) for NUI. There are no statistically differences in the left pre-frontal area (Fp1) for alpha activity.

Lower alpha activity appears statistically higher for UI in the left parietal area (P3), while it is statistically higher in the right one (P4) for NUI. There is no statistically difference in the center parietal area (Pz). Upper alpha activity appears statistically higher for UI in the left and center parietal areas (P3, Pz), while it is statistically

Table 4.1 Statistically significant power differences for the useful and non-useful items (significance threshold .05)

	Rhythms – activity			
Electrode position	θ	α-1	α-2	α
Fp1	NUI	UI	UI	–
Fp2	NUI	NUI	NUI	NUI
P3	UI	UI	UI	UI
Pz	UI	–	UI	UI
P4	NUI	NUI	NUI	NUI
O1	NUI	UI	NUI	NUI
O2	UI	UI	UI	UI

higher in the right one (P4) for NUI. Total alpha activity appears the same as upper alpha activity.

In the occipital area, lower alpha activity appears statistically higher for UI in both electrodes (O1, O2). Upper alpha appears statistically higher in both occipital electrode positions for NUI. Total alpha activity appears the same as lower alpha.

4.4 Discussion

This work presents the first neurophysiological results of female students watching affective visual stimuli in a digital learning environment concerning earthquake precaution measures.

Theta power signals in pre-frontal area were higher for the non-useful items and together with the prominent theta activity in frontal and frontal midline locations indicate information processing [24] and complex sensory stimuli regardless of the type of sensory input [4]. Probably the NUI demanded higher processing of visual information in a conceptual level in an effort to identify them as not necessary objects as far as it regards earthquake precaution measures. Moreover, the NUI activated the frontal cortex demanding mnemonic functions and visual selective attention [10]. Both useful and non-useful items required an increase of primary visual processing as theta activity indicates [12]. However, strong theta activity for NUI in both pre-frontal and occipital areas also indicates increased processing of visuo-spatial information against UI [10].

An increase of alpha activity has been proposed for predicting visual perceptual performance [5, 8, 22, 29], which is correct for both object categories, necessary (UI) and not necessary (NUI). Lower alpha activity (8–10 Hz) in FP1, P3, O1 and O2 positions was recorded with statistical significance for UI relative to NUI. This probably shows the participants' effort to encode the visual stimulus [15]. This result is confirmed by the fact that statistically significant differences of the UI in the occipital electrode position O2 for the lower alpha activity against the NUI suggesting the participants' effort to increase their attention and learn the useful items indicating also less mental effort and attentional demands for the UI [7, 18].

NUI theta signals are statistically significant against the UI in the left occipital electrode (O1), which indicates an increased cognitive effort for these items. The increase of the parieto-occipital alpha activity for NUI might be an indication of similar useful information processing and in particular of "searching, accessing, and retrieving information from long-term memory" [24]. Upper alpha activity (11–12 Hz) is statistically higher for the NUI against UI signals in the right prefrontal area (Fp2). This suggests that NUI besides primary visual processing activated higher brain functions such as memory and vigilance [8]. Changes in the alpha power can even determine whether a stimulus can be consciously detected or not [25]. An increasing of alpha activity has been proposed for predicting visual perceptual performance [5, 22, 28], which is valid for both groups of items.

Our results show that electric brain activity of the female participants is different for useful and non-useful objects. These findings indicate that the participants recognize all the ten objects, showed visual awareness and mental effort. They also made an effort to learn the useful items against the non-useful ones, for which they used certain memory functions in order to distinguish from the useful ones.

Our results show that educational neuroscience is a corroborative approach for assessing learning environments concerning disaster education. They also show that brain functions can be exploited for the design and use of technology enhanced learning [14].

Although brain imaging cannot lead directly to educational scenarios, "there is a need for bridging studies that interpret scientific results in terms of possible interventions, and evaluation of these interventions in suitable learning contexts" [14].

Acknowledgements This work has been partly financed by the Greek Ministry of Education and Religious Affairs, National Strategic Reference Framework, Operational Program "Education and Lifelong Learning", production of educational tools for earthquake and natural disaster prevention – DEUCALION.

References

1. Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: High-resolution EEG investigation of meditation. *Neuroscience Letters, 310*, 57–60.
2. Andreano, J., Liang, K., Kong, L., Hubbard, D., Wiederhold, B. K., & Wiederhold, M. D. (2009). Auditory cues increase the hippocampal response to unimodal virtual reality. *Cyberpsychology & Behavior, 12*(3), 309–313.
3. Antonenko, P., Paas, F., Grabner, R., & Gog, T. (2010). Using electroencephalography to measure cognitive load. *Educational Psychology Review, 22*(4), 425–438.
4. Basar, E., Basar-Eroglu, C., Karakas, S., & Schuermann, M. (1999). Are cognitive processes manifested in event-related gamma, alpha, theta and delta oscillations in the EEG? *Neuroscience Letters, 259*(3), 165–168.
5. Busch, N. A., Dubois, J., & VanRullen, R. (2009). The phase of ongoing EEG oscillations predicts visual perception. *Journal of Neuroscience, 29*(24), 7869–7876.
6. Cremades, J., Barreto, A., Sanchez, D., & Adjouadi, M. (2004). Human-computer interfaces with regional lower and upper alpha frequencies as on-line indexes of mental activity. *Computers in Human Behavior, 20*(4), 569–579.
7. Donner, T. H., Siegel, M., Oostenveld, R., Fries, P., Bauer, M., & Engel, A. K. (2007). Population activity in the human dorsal pathway predicts the accuracy of visual motion detection. *Journal of Neurophysiology, 98*(1), 345–359.
8. Ergenoglu, T., Demiralp, T., Bayraktaroglu, Z., Ergen, M., Beydagi, H., & Uresin, Y. (2004). Alpha rhythm of the EEG modulates visual detection performance in humans. *Cognitive Brain Research, 20*(3), 376–383.
9. Ferrari, M. (2011). What can neuroscience bring to education? *Educational Philosophy and Theory, 43*, 31–36.
10. Gruber, T., & Matthias, M. (2005). Oscillatory brain activity dissociates between associative stimulus content in a repetition priming task in the human EEG. *Cerebral Cortex, 15*(1), 109–116.

11. Gruber, T., Tsivilis, D., Giabbiconi, C. M., & Muller, M. M. (2008). Induced electroencephalogram oscillations during source memory: Familiarity is reflected in the gamma band, recollection in the theta band. *Journal of Cognitive Neuroscience, 20*(6), 1043–1053.
12. Hinterberger, T., Widman, G., Lal, T. N., Hill, J., Tangermann, M., Rosenstiel, W., Schölkopf, B., Elger, C., & Birbaumer, N. (2008). Voluntary brain regulation and communication with electrocorticogram signals. *Epilepsy & Behavior, 13*(2), 300–306.
13. Howard-Jones, P. A. (2011). A multiperspective approach to neuroeducational research. *Educational Philosophy and Theory, 43*, 24–30.
14. Howard-Jones, P., Ott, M., van Leeuwen, T., & De Smedt. B. (2010). *Neuroscience and technology enhanced learning*. Bristol: Futurelab. http://www.futurelab.org.uk/sites/default/files/NTEL_online_AW.pdf [visited 17-Sept-2013]
15. Jaušovec, N., & Jaušovec, K. (2000). EEG activity during the performance of complex mental problems. *International Journal of Psychophysiology, 36*, 73–88.
16. Kahana, M. J., Seelig, D., & Madsen, J. R. (2001). Theta returns. *Current Opinion in Neurobiology, 11*, 739–744.
17. Kelly, A. E. (2011). Can cognitive neuroscience ground a science of learning? *Educational Philosophy and Theory, 43*, 17–23.
18. Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews, 29*, 169–195.
19. Kober, S. E., & Neuper, C. (2011). Sex differences in human EEG theta oscillations during spatial navigation in virtual reality. *International Journal of Psychophysiology, 79*(3), 347–355.
20. Koizoumi, H. (2011). Brain-science based cohort studies. *Educational Philosophy and Theory, 43*, 48–55.
21. Kosslyn, S. M. (2005). Mental images and the brain. *Cognitive Neuropsychology, 22*, 333–347.
22. Mathewson, K. E., Gratton, G., Fabian, M., Beck, D. M., & Ro, T. (2009). To see or not to see: Prestimulus alpha phase predicts visual awareness. *The Journal of Neuroscience, 29*(9), 2725–2732.
23. Mikropoulos, T. A. (2003). Brain research in science education research. In D. Psillos, P. Kariotoglou, V. Tselfes, E. Hatzikraniotis, G. Fassoulopoulos, & M. Kallery (Eds.), *Science education research in the knowledge – Based society*. Dordrecht: Springer.
24. Onton, J., Delorme, A., & Makeig, S. (2005). Frontal midline EEG dynamics during working memory. *NeuroImage, 27*(2), 341–356.
25. Romei, V., Brodbeck, V., Michel, C., Amedi, A., Pascual-Leone, A., & Thut, G. (2008). Spontaneous fluctuations in posterior {alpha}-band EEG activity reflect variability in excitability of human visual areas. *Cerebral Cortex, 18*(9), 2010–2018.
26. Schacter, D. L. (1977). EEG theta and psychological phenomena: A review and analysis. *Biological Psychology, 5*, 47–82.
27. Shaw, R., Shiwaku, K., & Takeuchi, Y. (2011). *Disaster education*. Bingley: Emerald.
28. Siegel, M., Donner, T. H., Oostenveld, R., Fries, P., & Engel, A. K. (2007). High frequency activity in human visual cortex is modulated by visual motion strength. *Cerebral Cortex, 17*(3), 732–741.
29. van Dijk, H., Schoffelen, J. M., Oostenveld, R., & Jensen, O. (2008). Prestimulus oscillatory activity in the alpha band predicts visual discrimination ability. *Journal of Neuroscience, 28*(8), 1816–1823.
30. Walter, V. J., & Walter, W. G. (1949). The central effects of rhythmic sensory stimulation. *Electroencephalography and Clinical Neurophysiology, 1*, 57–86.
31. Zacharis, G. K., Mikropoulos, T. A., & Priovolou, C. (2013). Stereoscopic perception of women in real and virtual environments: A study towards educational neuroscience. *Themes in Science and Technology Education, 6*(2), 109–120.

Chapter 5
Interest and Disinterest from College Students for Higher Education in Sciences

Michel Pronovost, Caroline Cormier, Patrice Potvin, and Martin Riopel

5.1 Introduction

Because sciences plays an important role in our contemporary societies, through, for example, the omnipresence of the technological developments which arise from it, it is not surprising that several authors support that a scientific literacy for all the students is as important as artistic, literary or historic cultures [4, 11, 22]. In spite of this recognized importance for scientific formation, we observe a reduction in the interest for the scientific careers [18, 30]. In most of industrialized countries, this decrease of interest leads to a decrease of enrollment in science and technology university programs. Students' proportion in science and technology in universities have been continually decreasing for the last fifteen years, and an increasing gap is observed between the social demand and the offer in scientific and technical expertise [2, 5, 6, 14, 16].

M. Pronovost (✉)
Collège Jean-de-Brébeuf, 3200 Chemin de la Côte-Ste-Catherine,
Montréal, Québec, Canada H3T 1C1

Département de didactique, Université du Québec à Montréal (EREST),
C.P. 8888, Succ. Centre-ville, Montréal, Québec, Canada H3C 3P8
e-mail: michel.pronovost@uqam.ca

C. Cormier
Cégep André-Laurendeau, 1111 rue Lapierre, Ville Lasalle, Québec, Canada H8N 2J4
e-mail: caroline.cormier@claurendeau.qc.ca

P. Potvin
Département de didactique, Université du Québec à Montréal (EREST),
C.P. 8888, Succ. Centre-ville, Montréal, Québec, Canada H3C 3P8
e-mail: patrice.potvin@uqam.ca

M. Riopel
Département de didactique, Université du Québec à Montréal, Montréal, QC, Canada
e-mail: riopel.martin@gmail.com

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_5

We observe in particular this phenomenon in the United States [15], in the United Kingdom [29], in Australia [3], in Japan [8], in Canada [1] and almost everywhere worldwide. This report is confirmed by the OECD [16], which deplore that the domains of science and engineering are the least popular with less than quarter of the registrations at university. Furthermore, up to half of the students registered in science change program for other fields of study before the end of their schooling [17].

5.2 Theoretical Framework

Hidi and Renninger [10] proposed a four-phase model of interest development in which the phases are intended to be progressive for an individual. The first phase, triggered situational interest, is characterized by an effect of surprise for the student [24], is generally externally supported [28] and may be a precursor to the predisposition to re-make a commitment as in upper phases of interest [20]. The second level, maintained situational interest, is characterized by a personal commitment [9] and as at the previous phase it is generally externally supported [20] and could be a precursor in a predisposition to re-make a commitment and to reach an upper level of interest [9]. At the third level, emerging individual interest, students are willing to perform tasks without being obligated to and even to exceed requirements because the topic interest them enough to stimulate their curiosity [20]. Even if it is mostly self-generated, an emerging individual interest needs to be somewhat externally supported [10]. Finally, at the highest level, the well-developed individual interest, students mobilise their resources to solve complex problems [20], they provide efforts without being aware of it and develop their self-regulation [13]. A student who reaches this level is going to persevere in his work, even if he were to meet obstacles [19]. Research has shown that interest for school and particularly for science and mathematics decrease as students get older [31].

For motivation aspects, Sanfeliz and Stalzer [25] suggest that self-determination and self-efficacy play an important role in the learning of science. They both are strongly associated to intrinsic motivation.

Self-determination is the ability to make a decision for oneself without influence from outside in order to satisfy the innate psychological needs for autonomy and competence [12].

Self-efficacy is an "individual's judgments of his or her capabilities to perform given actions" [23].

On the other hand, grade motivation is a factor associated with extrinsic motivation. Students with this kind of motivation actually have a greater tendency to stay in school than students with an absence of motivation [7]. But even if it could be a strong source of motivation because many universities select their candidates on the basis of their grades, grade motivation cannot be sufficient for science students to overcome a lack of intrinsic motivation towards science. Previous research has shown that grade motivation is in fact the least important factor to describe motivation towards science in non-science major students [7].

At the other end of the motivation spectrum is amotivation, associated with the intention of dropping out of school [32]. Amotivation occurs when a student perceives non-contingency between his or her own action and the outcomes. He is simply not motivated [26].

5.3 Methodology

This study was conducted to trace a portrait of pre-university college students regarding their perception of science education in high school and to measure their interest for science education. For this purpose, 1164 first-year college students (age 17–18, average 17.4) answered the Interest and Disinterest Questionnaire about Science (IDQS) developed for this study. This instrument measured their interest and motivation towards science with 45 Likert-type items about their experiences in science class during the previous year, when they were still in high school. To add richness to the analysis, open-ended questions were also included in the IDQS, asking students to describe positive and negative experiences in science classes, as well as their opinion about learning science in high school.

The sample was selected from a possible total of 24,000 students in 15 pre-university colleges in the province of Quebec, Canada. For each school, teachers were asked to pass the IDQS to entire classrooms of students. The sampling was therefore convenience. Of the 1164 students in total, 737 (65.2 %) were enrolled in a science college program, whilst 394 (34.8 %) of them were enrolled in a non-scientific program.

A majority of female answered the IDQS (60.4 %), which is representative of the female proportion in post-secondary education in Quebec [27].

Data analysis pursued two ends: first, scores from the various items were statistically analysed using IBM SPSS Statistics (version 22) to compare science and non-science students regarding their interest and disinterest towards science. Secondly, open-ended answers concerning reasons for this interest or disinterest were qualitatively analysed to categorise reasons and to deepen conclusions obtained from the statistical analysis.

5.4 Results

5.4.1 Interest

Scores for each phase of development of interest was compiled from different items of the IDQS. Table 5.1 presents Cronbach coefficient and number of items for each score. These results show good internal consistency for all scores.

We observe in Table 5.2 that science students have a superior score of interest for science on average compared to non-science students for all four levels. All the difference observed are highly significant.

Table 5.1 Cronbach coefficients and number of items for each interest scores

Scores	Alpha Coeff.	Nb items
Triggered situational interest score	.689	7
Maintained situational interest score	.745	5
Emerging personal interest score	.697	6
Developed personal interest score	.706	6

Table 5.2 Statistical differences in average score of interest for science (S) students and non-science (NS) students

Scores	Gr.	*N*	Mean	SD	*t*	*p*
Triggered situational interest	NS	393	.5407	.1955	−9.472	<.001
	S	737	.6507	.1668		
Maintained situational interest	NS	393	.3830	.1945	−19.868	<.001
	S	737	.6177	.1862		
Emerging personal interest	NS	393	.4609	.7760	−16.352	<.001
	S	737	.6360	.1689		
Developed personal interest	NS	393	.3853	.1831	−12.073	<.001
	S	737	.5235	.1833		

Table 5.3 Statistical differences in average score of interest for male (M) and female (F) students

Scores	Gr.	*N*	Mean	STD	*t*	*p*
Triggered situational interest	M	450	.6255	.1802	1.967	.049
	F	686	.6036	.1870		
Emerging personal interest	M	450	.5932	.1901	2.467	.014
	F	686	.5646	.1910		

Table 5.3 shows that male students have higher triggered situational interest and higher emerging personal interest in science than female students. The difference between the two groups is not significant for the other two scores.

5.4.2 *Motivation*

Scores were made for different levels of motivation from items. Table 5.4 presents Cronbach coefficient and number of items for each level. These results show good internal consistency for amotivation score and acceptable consistency for the self-efficacy score.

Table 5.6 shows that male students are more amotivated and that have more self-efficacy than female students. Female students have, on the other hand, higher scores on self-determination and grade motivation. All the difference observed are highly significant.

Table 5.4 Cronbach coefficients and number of items for each motivation scores

Scores	Alpha Coeff.	Nb items
Amotivation	.783	3
Self-determination	n/a	1
Grade motivation	n/a	1
Self-efficacy	.660	3

Table 5.5 Statistical differences in average score of motivation for science (S) students and non-science (NS) students

Scores	Gr.	*N*	Mean	STD	*t*	*p*
Amotivation	S	736	.1454	.2301	12.062	<.001
	NS	392	.3033	.1637		
Self-determination	S	736	.7463	.2609	7.140	<.001
	NS	392	.6273	.2768		
Grade motivation	S	737	.8740	.2144	12.699	<.001
	NS	392	.6697	.2775		
Self-efficacy	S	736	.6664	.2018	13.851	<.001
	NS	392	.4720	.2358		

Table 5.6 Statistical differences in average score of motivation for male (M) and female (F) students

Scores	Gr.	*N*	Mean	STD	*t*	*p*
Amotivation	M	449	.1700	.1987	4.000	<.001
	F	685	.2191	.2043		
Self-determination	M	449	.6278	.2875	−8.009	<.001
	F	685	.7566	.2488		
Grade motivation	M	450	.7650	.2770	−4.065	<.001
	F	685	.8298	.2389		
Self-efficacy	M	449	.6459	.2236	5.580	<.001
	F	685	.5687	.2343		

We observe in Table 5.5 that science students are less amotivated, have superior scores in self-determination, self-efficacy and grade motivation. All the difference observed are highly significant.

5.4.3 Positive and Negative Experiences

Answers to the open-ended questions of the IDQS are particularly interesting in the light of the differences observed in interest for science. When asked to describe positive and negative experiences they had in science in high school, students described events that were similar in nature and frequency whether they are still studying in sciences or not. The most frequent positive experiences are associated

Table 5.7 Number of students invoking their science teachers in a positive or a negative experience in high school for science (S) students and non-science (NS) students

Experience	Gr.	*N*	%
Positive	S	163	22.1 %
	NS	41	10.4 %
Negative	S	153	20.8 %
	NS	43	10.9 %
Positive and negative	S	76	10.3 %
	NS	12	3.04 %

Table 5.8 Negative experiences mostly invoked by science (S) students and non-science (NS) students

Negative experience	Gr.	*N*	Total number of responses	%
Self perception, difficulty of curriculum	S	155	765	20.3 %
	NS	52	261	19.9 %
Lacking interest of curriculum	S	121	765	15.8 %
	NS	55	261	21.1 %

with their relation to the teachers and their laboratory classes. The most frequent negative experiences were also associated with the relation to their teachers, to the curriculum and their self-perception related to the perceived difficulty of the curriculum.

It is interesting to note that teachers are very important for high school students, as they can leave a positive or a negative impression on them. It is also worth noting that oftentimes, the same student would describe both a positive and a negative experience about teachers. In Table 5.7, occurrences of evoking a science teacher are presented.

Surprisingly, students that reported a negative experience related to the difficulty of the science curriculum were equally enrolled in a scientific or a non-scientific program in college. This observation is striking since one could have presumed that students that felt the science contents were difficult might have dropped out of science in college, but our results suggest that it is not a decisive reason for them.

Table 5.8 shows those very similar percentages for the perception of difficulty, and again very close percentages for the lack of interest in the science curriculum for science and non-science students.

5.4.4 Favourite and Least Favourite Classes

Students were also asked what had been their favourite class throughout high school, and what had been their least favourite one. For these questions, results were opposite from science students and non-science students regarding to science classes, as presented in Table 5.9.

Table 5.9 Favourite and least favourite classes in high school for science (S) students and non-science (NS) students

Classes	Gr.	*N*	Total number of responses	%
Science as favourite	S	364	687	53.0 %
	NS	58	367	15.8 %
Science as least favourite	S	129	718	18.0 %
	NS	188	380	49.5 %

For these items as well as those for positive/negative experiences, reasons for the preferences were self-perception and difficulty or easiness of the curriculum, as well as the personal interest or disinterest towards the topics. Furthermore, some students, mostly in science programs, invoked the positive and the intellectual stimulation as a reason for their preference of science classes.

5.5 Discussion

Interest towards science is very different for science and non-science students. Science students demonstrate all four phases of interest development at a higher level than non-science students. This shows that not only science students are more interested in general than non-science students, but furthermore that whenever an item of the IDQS asked them if a situation would interest them or not, they would answer more positively than non-science students. This is somewhat expected, as science students are altogether in a science program in college. However, when the scores are observed for each group, we can see that the phase of interest obtaining the greater score is "triggered situational interest" for both science and non-science students. This is in line with results of previous researches showing that interest towards science tends to decrease with age in general [31], being here at the lowest phase for students of 17–18 years old.

Students' attitude towards science can be variable depending on the tasks proposed to them and the way science is taught [33]. When they feel more involved in their classes, students' attitude can improve [9], which underlines the importance of their teachers in the process, as the results to the open-ended questions confirmed.

Considering their motivation, science students not only are more intrinsically motivated, as is shown by their higher score of self-determination, but also have a better perception of their own capabilities, as their higher self-efficacy score is showing. This observation is what is expected from science students. When they answered the open-ended questions, however, they still felt pretty strongly that science classes are difficult. Our results show that even if these students think science classes are difficult, they would still persevere, probably because of their high level of self-efficacy.

Science students score for grade motivation is higher than non-science students and their amotivation score is lower. This was expected, as grade motivation is associated with continuing one's education to obtain a university degree, whilst amotivation is associated with dropping out of school.

During the next steps of this study, we will compare these declared perceptions to the actual grades of the students. This next data collection will be particularly important to distinguish between high-achieving students, their interest and motivation, and the interest and motivation of more grade-challenged students.

Acknowledgements This research was granted by Quebec's *Ministère de l'Enseignement supérieur, de la Recherche, de la Science et de la Technologie* through PAREA and PSCCC and *Centre de recherche interuniversitaire sur la formation et la profession enseignante - Université du Québec*.

References

1. Bordt, M., DeBroucker, P., Read, C., Harris, S., & Zhang, Y. (2001). Determinants of science and technology skills: Overview of the study. *Education Quarterly Review, Statistics Canada, 1*, 8–11.
2. CST, Conseil de la science et de la technologie. (2004). *La culture scientifique et technique au Québec: une interface entre les sciences, la technologie et la société. Rapport de conjoncture 2004*. Québec: Conseil de la science et de la technologie.
3. Dekkers, J., & DeLaeter, J. (2001). Enrolments trends in school science education in Australia. *International Journal of Science Education, 23*, 487–500.
4. Feinstein, N. (2011). Salvaging science literacy. *Science Education, 95*, 168–185.
5. Foisy, M., & Gingras, Y. (2003). « La désaffection des jeunes pour les sciences : réalité ou fiction ? » in B. Schiele et R. Jantzen (dir.), Les territoires de la culture scientifique (pp. 143–194). Montréal/Lyon: Presses de l'Université de Montréal et Presses de l'Université de Lyon.
6. Garnier, C., Marinacci, L., Vincent, S., Gauthier, D., St-Jean, M., Patenaude, J., Quesnel, M., Hall-Gnom, V., Bonenfant, C., & Séguin-Noël, H. (2004). Système de représentations sociales et de pratiques éducatives en science et technologie au secondaire. Rapport de recherche. GEIRSO, Université de Montréal.
7. Glynn, S. M., Taasoobshirazi, G., & Brickman, P. (2009). Science motivation questionnaire: Construct validation with non-science majors. *Journal of Research in Science Teaching, 46*(2), 127–146.
8. Goto, M. (2001). Japan. In *International Bureau for Education, Science Education for Contemporary Society: Problems, Issues and Dilemmas* (pp. 31–38). Geneva: IBE, UNESCO.
9. Harackiewicz, J. M., Barron, K. E., Tauer, J. M., Carter, S. M., & Elliot, A. J. (2000). Short-term and long-term consequences of achievement: Predicting continued interest and performance over time. *Journal of Educational Psychology, 92*, 316–330.
10. Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127.
11. Kelly, G. J. (2011). Scientific literacy, discourse, and epistemic practices. In C. Linder, L. Ostman, D. A. Roberts, P. Wickman, G. Erikson, & A. McKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 61–73). New York: Routledge.
12. Legault, L., Green-Demers, I., & Pelletier, L. (2006). Why do high school students lack motivation in the classroom? Toward an understanding of academic amotivation and the role of social support. *Journal of Educational Psychology, 98*(3), 567.

13. Lipstein, R., & Renninger, K. A. (2006). “Putting things into words”: 12–15-year-old students' interest for writing. In P. Boscolo & S. Hidi (Eds.), *Motivation and writing: Research and school practice*. New York: Kluwer Academic/Plenum.
14. MELS. (2006). Évaluation de l'application du programme de formation de l'école québécoise – Enseignement primaire. Rapport préliminaire de la Table de pilotage du Renouveau pédagogique. Québec : MELS.
15. National Science Foundation. (2002). Science and Engineering Indicators 2002, online at http://www.nsf.gov/sbe/srs/seind02/c0/c0s1.htm. Accessed 4 Mar 2004.
16. OCDE. (2011). *Regard sur l'éducation. Les indicateurs de l'OCDE*. Paris: OCDE.
17. Pearson, W., & A. Fechter. (Eds.). (1994). Who will do science?: Educating the next generation. Baltimore: Johns Hopkins University Press.
18. Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: A systematic review of 12 years of educational research. *Studies in Science Education, 50*(1), 85–129.
19. Renninger, K. A., & Leckrone, T. (1991). Continuity in young children's actions: A consideration of interest and temperament. In L. Oppenheimer & J. Valsiner (Eds.), *The origins of action: Interdisciplinary and international perspectives* (pp. 205–238). New York: Springer.
20. Renninger, K. A., & Hidi, S. (2002). Student interest and achievement: Developmental issues raised by a case study. In A. Wigfield & J. S. Eccles (Eds.), *Development of achievement motivation* (pp. 173–195). New York: Academic.
21. Renninger, K. A., & Shumar, W. (2004). The centrality of culture and community to participant learning at and with the Math Forum. In S. A. Barab, R. Kling, & J. H. Gray (Eds.), *Designing for virtual communities in the service of learning* (pp. 181–209). New York: Cambridge University Press.
22. Roberts, D. (2007). Scientific literacy/science literacy. In S. K. Abellet & N. G. Lederman (Eds.), *International handbook of research on science education* (pp. 729–780). Mahwah: Erlbaum.
23. Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology, 25*(1), 54–67.
24. Sadoski, M. (2001). Resolving the effects of concreteness on interest, comprehension, and learning important ideas from text. *Educational Psychology Review, 13*, 263–281.
25. Sanfeliz, M., & Stalzer, M. (2003). Science motivation in the multicultural classroom. *The Science Teacher, 70*(3), 64–66.
26. Schunk, D. H. (1991). Self-efficacy and academic motivation. *Educational Psychologist, 26*, 207–231.
27. Service régional d'admission du Montréal Métropolitain. (2012). *Rapport annuel, année 2011–2012*. SRAM.
28. Sloboda, J. A. (1990). Musical excellence—How does it develop? In M. Howe (Ed.), *Encouraging the development of exceptional skills and talents* (pp. 165–178). Leicester: British Psychological Society.
29. Smithers, A., & Robinson, P. (1988). *The growth of mixed a levels*. Oxford: Department of Education, University of Manchester.
30. Su, S., Ortony, A., & Revelle, W. (2012). *Journal of Research in Science Teaching, 49*(4), 515–537.
31. Tracey, T. J. G. (2002). Development of interests and competency beliefs: A 1-year longitudinal study of fifth- to eight-grade students using the ICA-R and structural equation modeling. *Journal of Counseling Psychology, 49*(2), 148–163.
32. Vallerand, R. J., Pelletier, L. G., Blais, M. R., Briere, N. M., Senecal, C., & Vallieres, E. F. (1992). The academic motivation scale: A measure of intrinsic, extrinsic, and amotivation in education. *Educational and Psychological Measurement, 52*(4), 1003–1017.
33. Zacharia, Z., & Barton, A. (2004). Urban middle-school students' attitudes toward a defined science. *Science Education, 88*, 197–222.

Part II
New Technologies in Science and Technology Education

Introduction

The second part of this book is called 'New Technologies in Science and Technology Education'. The chapters addressing this theme raise important issues that involve up-to-date best practices and theoretical concerns on the development and application of technology-enhanced learning environments as a means to enhance science and technology education. Through current research studies, important issues are raised ranging from the design process of the genesis of learning artifacts to virtual scaffolding, inquiry and problem-solving methods embedded in computer-based learning environments and exemplary educational interventions are presented of educational video games, video recorded experiments, shared workspaces platforms and physical and virtual manipulatives that aim to give us an insight into the applicability and purpose of their inclusion in the learning process. The chapters elaborate on the affordances and potentials of these learning environments and tools as well as the underpinning approaches and methodologies on which they are grounded.

Improvement of Inquiry in a Complex Technology-Enhanced Learning Environment revisits the issue of necessity for the application of more engaging learning methods such as inquiry and problem solving, in science and mathematics education. It demonstrates the use of a complex technology-enhanced learning environment, SCY-Lab, in enhancing students' inquiry knowledge and skills. In the SCY-Lab learning environment, students are engaged in reflective inquiry activities that facilitate their analysis of their learning process and trigger them to consider alternative solutions for their inquiry in order to learn from experiences. The chapter reports that students' general inquiry knowledge, transformative inquiry skills and domain-related knowledge improved statistically significantly in applying the SCY learning environment.

The chapter *Five Powerful Ideas about Technology and Education* is an account of both theoretical and practical issues raised by the penetration of technology in education. The author elaborates on powerful ideas such as computational media and new literacies, re-mediation, engagement and activity structures and open toolsets and stresses on their complexity and the necessity for technical and cultural innovations to realize a powerful, infrastructural literacy. The chapter is particularly interesting because it elaborates on the potentials of technology and its long-term impact on the educational process, grounded on its affordances in raising students' engagement and bringing to the surface 'intelligences that are near-dormant with conventional media'.

The next chapter entitled *Analysis of an Inquiry-Based Design Process for the Construction of Computer-Based Educational Tools: The Paradigm of a Secondary Development Tool Negotiating Scientific Concepts* explores the manipulation of educational tools in designing targeted learning artifacts. The research study gives us an insight into the design process followed by a student teacher engaged in the development of a Microworld that negotiates scientific concepts related to the cognitive module of kinematics and dynamics in Physics. The chapter provides a thorough record of the designer' application of the pedagogical, Technological and content knowledge parameters during the design process and elaborates on the perspective of interaction between the designer's cognitive and creative background along with the authoring template. The explicit analysis of the design process raises a challenging issue on the design specifications that should be addressed while being engaged in the development of educational artifacts.

Scaffolding for Inquiry Learning in Computer-Based Learning Environments elaborates on the innovative approach of virtual scaffolding in computer-based learning environments. The research study examines three different computer-based learning environments in terms of their embedded explicit and implicit scaffolding types. The authors make an explicit analysis of the types and role of scaffolding designed and emerged from different computer-based learning environments and give us an insight on the derived learning outcomes as well as the way the scaffolding types support student inquiry learning.

The chapter titled *Multimedia applications by using video recorded experiments for teaching Biology in secondary education* reports on the use of multimedia applications for the enrichment of Biology e-textbooks in secondary education in Greece. These specific applications are recorded videos of experiments realized in a biology laboratory and they are part of a multimedia and interactive application which uses texts, images and tests aiming to enhance both the practical and theoretical aspects of science. Their use is reported to play a significant cognitive and motivational role in science education and allow for student reflection through the immediate visual feedback they provide.

The activation and enhancement of students' engagement and meaning generation through the application of new pedagogic approaches have been focal points in Science education research for many years now. The authors of the chapter titled *Inquiry and Meaning Generation in Science While Learning to Learn Together: How Can Digital Media Provide Support?* explore this important issue by applying the 'learning to learn together' (L2L2) social meta-cognition approach through a shared workspaces platform and a Newtonian Physics microworld as a solid ground for meaningful interaction. The chapter reports on the findings of a design-based research study carried out in the framework of a multi-organizational European

R&D project titled 'METAFORA'. The innovative approach of the study results in challenging findings that demonstrate a strong relation between L2L2 processes in Science Education and meaning generation when implementing a platform of shared workspaces.

Using Physical and Virtual Manipulatives to Improve Primary School Students' Understanding of Concepts of Electric Circuits explores the use of blended combinations of physical (PM) and virtual manipulatives (VM) in enhancing the conceptual understanding of primary school students. The chapter builds on an existing framework and discourse that takes into consideration the PM and VM affordances and the research design applied for undergraduate students. The findings of the research indicate that the use of a blended combination of physical and virtual manipulatives are more conducive to sixth graders conceptual understanding of the electric circuits concepts than the use of each kind of manipulatives in isolation.

The final chapter in part II is called *Impact of Educational Video Game on Students' Conceptions related to Newtonian Mechanics* and explores the challenging issue of embedding video games in science education. The research study examines the impact of Mecanika, an educational video game about the principles of Newtonian mechanics, in engaging students in active exploration of core science concepts. The innovative and challenging issue that is raised concerns the way that this genre of learning games should be applied in order to have the best learning outcomes. Based on the results of this research study, students by being engaged in playing the game, even without active involvement from teachers or guidebooks, can yield better learning outcomes than more traditional instruction.

Chapter 6
Improvement of Inquiry in a Complex Technology-Enhanced Learning Environment

Margus Pedaste, Külli Kori, Mario Mäeots, and Ton de Jong

6.1 Introduction

Science and mathematics education is named by the European Union as a key facilitator in achieving innovation [14]. However, in this case, changing the learning methods is necessary for them to become more engaging—to apply inquiry and problem solving methods. In Estonia, these approaches have been applied through preservice and in-service teacher education, changes in national curricula, and development of technology-enhanced learning environments for more than 10 years. These changes could be the reasons why Estonia has very good outcomes according to international PISA tests and why these have been significantly improved during the last years [8]. Estonia is on the sixth position according to average science scores among all countries participating worldwide and has improved by 14 points. Although in 2009 one of the main issues was that comparatively fewer students were on the top level in their science knowledge and skills, in 2012, Estonia was among the few countries where the share of top performers in science has increased between 2009 and 2012 (from 10.4 to 12.5 %), and Estonia is the second

M. Pedaste (✉) • K. Kori
University of Tartu, Salme 1a 50103, Tartu, Estonia
e-mail: margus.pedaste@ut.ee; kulli.kori@ut.ee

M. Mäeots
Faculty of Social Sciences and Education, Institute of Education,
University of Tartu, Tartu, Estonia
e-mail: mario.maeots@ut.ee

T. de Jong
Faculty of Behaviourial, Management & Social sciences, University of Twente,
Enschede 7500AE, The Netherlands
e-mail: a.j.m.dejong@utwente.nl

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_6

country in Europe after Finland based on percentage of students reaching the two highest levels of proficiency in science.

One of the reasons for these changes could be the introduction of new science curricula (separately in general science, biology, physics, chemistry, and geography) in 2009, where problem-based and inquiry-based learning have been encouraged thoroughly. For more than 10 years, problem-solving skills and inquiry learning approach have been introduced and practically applied in both preservice and in-service teacher education. This approach has been a key topic in many teachers' conferences and seminars in Estonia. In addition, several web-based learning materials (e.g., Young Scientist http://bio.edu.ee/noor/ and Young Researcher http://bio.edu.ee/teadlane/ [6, 7]) or robotics [2] have been developed for applying inquiry learning in the classroom and in national competitions for students.

In general, it has been demonstrated that inquiry learning is more effective in comparison with more "traditional" learning approaches, such as direct instruction or open discovery [1, 4]. However, it is not often widely applied worldwide in schools because it is not easy to change teachers' attitudes toward inquiry, which is often time consuming and unpredictable. Therefore, technology-enhanced learning environments that can be applied by the students with only minimal help from teachers are needed. One of the main issues in applying these learning environments is their complexity. In the current study, we were interested in how a complex technology-enhanced learning environment can be applied to improve students' inquiry knowledge and skills.

According to a theoretical model of inquiry [7], a complex learning environment should effectively support three types of processes: meta-processes, regulative processes, and transformative processes. All processes are activated through meta-processes, and for this general inquiry, knowledge is needed. A main result of inquiry should be the improvement of inquiry skills and the acquisition of new domain knowledge. Therefore, we were interested in our study in these three components when characterizing students' progress: general inquiry knowledge, transformative inquiry skills, and domain-related knowledge.

In our study, we used the learning environment SCY-Lab [3], which is a complex technology-enhanced learning environment where students complete different "missions". On these missions, they apply a specific learning scenario, for example, an inquiry-based learning scenario in the learning module applied in our study [see 13]. On this mission, students solve a problem using the inquiry approach. They formulate research questions and hypotheses, read theories about their topic, plan an experiment, collect data and analyze them, and make inferences and conclusions. Students' learning is supported by several tools and scaffolds, and in specific activities, peers' support is available. This learning environment was developed as an outcome of a European project, Science Created by You (SCY), to meet the needs in many countries. The inquiry process in the SCY-Lab ecology mission is supported by reflection questions. Our hypothesis was that this is a way to enhance students' inquiry, and therefore, their knowledge and skills improve more by using SCY-Lab. The following research questions were formulated:

1. Is there a significant improvement in students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge in using the complex technology-enhanced learning environment SCY-Lab?
2. How are the skills and the knowledge of the inquiry model related with each other in using SCY-Lab?

6.2 Learning Environment

In this study was used a web-based inquiry-learning environment SCY-Lab (http://www.scy-net.eu/). It is a technology-enhanced learning environment students learn by completing "missions" where they create products that can be shared and discussed with their peers. Among several SCY missions, an ECO mission was selected for the current study. It is for 15–19-year-old students and primarily addresses ecology topics. The ECO mission supports combining hands-on data collection with web-page activities that are supported by inquiry approach. In each mission, inquiry approach is divided into learning activity spaces where students are provided with a pre-defined set of assignments, guidelines, and tools for creating "products", e.g. a hypothesis, experimentation plan, data set, inference, or problem solution.

The ECO mission presents to the learners four sub-missions and each of them is divided in three learning activity spaces: to create a hypothesis, inferences, and problem solution. Each of these four sub-missions focuses on a specific domain: (1) nutrients and primary production, (2) the role of light in ecosystems, (3) relationships between trophic levels, and (4) pH and aquatic ecosystems. In this study the role of light in ecosystems was studied. On this mission, students had to define a problem based on a story, then they had to specify more specific research questions and hypotheses. Next, students had to draw an experiment plan and conduct this experiment using real equipment for data collection. Later, real data collected with mobile Vernier devices was imported to the SCY-Lab for analysis and drawing inferences. The inferences were finally used for solving the problem defined in the beginning of the inquiry cycle. In each of the inquiry stages, students were provided with specific guidelines. In these stages, students' transformative inquiry skills as well as their skills to regulate their inquiry process were supported by written guidelines.

6.3 Methods

A SCY-Lab mission about investigating the effect of light intensity on photosynthesis was applied by four classes in four schools in Estonia. The classes were selected by teachers who voluntarily participated in the study. Fifty-four students (aged 14–18 years) completed the mission and filled in prequestionnaires and postquestionnaires for describing their general inquiry knowledge, transformative inquiry skills, and domain-related knowledge. In addition, students' reflection of inquiry was guided in the learning environment by specific supportive questions. Thus, guided inquiry and reflection were seen as the main factors supporting students' inquiry process.

Prequestionnaires and postquestionnaires were used to evaluate students' general inquiry knowledge through asking them to sequence the stages of inquiry and to explain why each of them is important in the inquiry process. Transformative inquiry skills were evaluated through asking the students to formulate two research questions, hypotheses, and inferences. Therefore, they were provided with a story about a problem and data presenting results of a study. In scoring the answers, a scale developed by Pedaste and Sarapuu [12] was applied. Students' domain-related knowledge was assessed with two open-ended questions about why an ecosystem needs light and what the importance of photosynthesis is. Students' reflection activities were facilitated through the following questions: (1) How often they did analyze their learning process? (2) How important was the analysis for them and why? (3) If they would do something differently next time in the inquiry process, what would it be? And finally, after completing all individual tasks, an open-group interview was conducted to obtain qualitative data about the positive and the negative aspects discovered during the learning phase.

In the case that the students completed only some of the four sections of the questionnaire, the incomplete parts were excluded. However, these students still had the opportunity to express their ideas in group interviews.

Students' improvement in general inquiry knowledge, transformative inquiry skills, and domain-related knowledge was analyzed using *t* test. The relationships among different types of knowledge and skills were found with Spearman's rank-order correlation. Interview transcripts were analyzed using inductive content analysis.

6.4 Results and Discussion

The results of the study showed that students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge significantly improved statistically when applied in SCY learning environment (see Table 6.1).

These results show that general inquiry knowledge had the highest initial level and domain-related knowledge had the lowest. This supports the application of the

Table 6.1 Level of students' general inquiry knowledge (GIK), transformative inquiry skills (TIS), and domain-related knowledge (DRK)

Knowledge or skill	Initial level (%)	Post-level (%)	t	p
GIK	78	87	−6.6	<0.01
TIS	53	67	−8.3	<0.01
DRK	33	44	−6.4	<0.01

general inquiry model well [7], where first, general inquiry knowledge is necessary to activate transformative inquiry skills that are needed in transformative inquiry processes to gain new domain-related knowledge or reconstruct existing knowledge structures. It was especially remarkable that using SCY-Lab improved all types of knowledge and skills whatever their initial level was. We argue that there were at least three reasons for this, and these can be suggested in designing complex technology-enhanced learning environments for inquiry learning.

1. Based on interview data, SCY-Lab had a clear structure that has, according to students' feedback, simple menus for navigation, clear guidelines, and an interesting and nice design. As students said in interviews, "it is easy to learn a topic with this learning environment," or "everything is clearly explained."
2. It was designed according to the inquiry cycle that has been proven to be effective in supporting students' inquiry skills [see 1, 4, 6, 7].
3. It contained reflection questions and task-embedded guidelines on regulative and transformative inquiry processes that have been regarded as effective facilitators of inquiry learning [see 5, 11].

More could be said about students' reflection activities. It appeared that most of them were rather positive toward reflection and applied particular activities frequently. Of 54 students, 43 reported in the prequestionnaire that they analyzed their learning process, and 25 of them did it often during the process. In the postquestionnaire, the number of students who did not analyze their learning process decreased by four. Even more of the students regarded analysis of the learning process as an important activity to ensure successful learning: 48 students in the prequestionnaire and 49 students in the postquestionnaire of 54 students. Respectively, 35 and 37 students even explained why they believe that this is important. The most frequent responses were the following: (1) it helps to correct mistakes and to perform more successfully next time (17 answers in the prequestionnaire and 14 in postquestionnaire), (2) it helps to understand what went well or bad (9 and 5 answers, respectively), and (3) it provides an overview about the work (6 and 8 answers, respectively).

More than half of the students (32 of 54 in the prequestionnaire and 31 of 54 in the postquestionnaire) also reported that they considered what to do differently next time in the inquiry process. The most common answers were that next time, they would think more deeply (8 answers in the prequestionnaire and 3 in the postquestionnaire), provide more complete answers (5 and 6 answers, respectively), analyze more (3 and 6 answers, respectively), and plan more their time (4 answers in both cases).

The second research question of interest was about the relationship between general inquiry knowledge, transformative inquiry skills, and domain-related knowledge. We hypothesized that finding pieces of evidence to the inquiry model proposed by Mäeots and Pedaste is possible [7].

The initial level of general inquiry knowledge correlated positively with that of domain-related knowledge in the prequestionnaire and postquestionnaire ($\rho = 0.39$ and $\rho = 0.41$, respectively, $p < 0.05$). The postlevel of general inquiry knowledge also correlated positively with that of domain-related knowledge, but it also significantly correlated statistically with the postlevel of transformative inquiry skills ($\rho = 0.43$, $p < 0.05$). First, it demonstrates that general inquiry knowledge could be important in increasing content-related learning gain in the inquiry process. Second, it was interesting that the correlation between general inquiry knowledge and the initial level of transformative inquiry skills was smaller compared with the correlation with the postlevel and not statistically significant. This result could show that general inquiry knowledge and transformative inquiry skills could be not related directly, but their relationship appears more explicitly in deeper analysis of the process of inquiry. It could demonstrate that general inquiry knowledge is needed to activate meta-processes as it is described according to a model of inquiry [7].

In addition, it was found that the learning gain of knowledge and skills in the inquiry process is the higher the lower it is in the beginning of the learning process. It is an expected result that has been described earlier in the context of problem solving [9, 10]. Pretest and posttest correlations were, in the case of general inquiry knowledge, 0.66; in the case of transformative inquiry skills, 0.88; and in the case of domain-related knowledge, 0.75 (all correlations were statistically significant at the level $p < 0.01$). Thus, the SCY-Lab ecology mission seems to support inquiry even if the initial knowledge and skills of students are not very high. A reason for this could be the active reflection of inquiry. According to the analysis on reflective activities, most of the students say that the analysis of their learning process is an important activity, and they analyze their inquiry and consider alternative solutions for their inquiry after the process to learn from their experiences.

According to our empirical findings and the theoretical inquiry model described by Mäeots and Pedaste [7], we can draw a figure describing the learning process in the SCY-Lab (Fig. 6.1).

Our empirical findings only show the relationships between different variables on the model of inquiry, and the influence of particular factors on others can only be

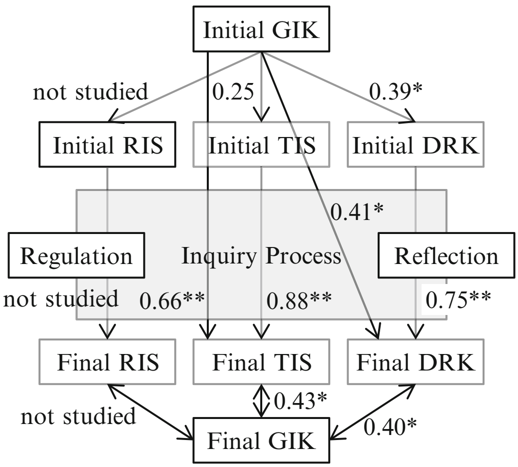


Fig. 6.1 Relationships in the inquiry model. A synthesis of empirical data and theoretical model of inquiry. *GIK* general inquiry knowledge, *RIS* regulative inquiry skills, *TIS*, transformative inquiry skills, *DRK* domain-related knowledge. *Statistically significant correlations, $p < 0.05$, **Statistically significant correlations, $p < 0.01$

hypothesized theoretically. As a result of the synthesis of empirical and theoretical findings, the inquiry process can be characterized in the following ways:

1. General inquiry knowledge is needed to activate inquiry processes by integrating initial regulative and transformative inquiry skills and domain-related knowledge.
2. Inquiry processes are supported by activities of regulation and reflection.
3. Students' inquiry skills and domain-related knowledge improve as a result of inquiry.
4. Their improved skills and knowledge help them to revise their general inquiry knowledge, and this revision is important to ensure additional improvement of their final knowledge and skills.

6.5 Conclusion

Our study demonstrated that the ecology mission in the SCY-Lab learning environment is a good example for understanding how a complex technology-enhanced learning environment should be designed. A significant improvement was found in students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge in using a complex technology-enhanced learning environment SCY-Lab. Some empirical pieces of evidence to support the theoretical inquiry model proposed by Mäeots and Pedaste [7] were also discovered. Several statistically significant correlations between initial and final inquiry skills and general inquiry knowledge or domain-related knowledge were found. These results made it possible to characterize the learning process in SCY-Lab at a more generalized level, and therefore, our findings can be used by other designers of learning environments and teachers. The designers are encouraged to guide inquiry by providing support on general inquiry knowledge. One option is to structure a learning environment according to inquiry phases and to provide guidance on transformative and regulative inquiry processes in each of these. In addition, the guidance on reflection should be considered. The teacher should learn from our findings that the effect of the inquiry process depends on a continuum—different types of knowledge and skills are often related with each other, and focusing on improving only one specific aspect might not be successful. It is very important that even domain-related knowledge is related to general inquiry knowledge.

Despite the applicability of the results of the current study, there are also several implications for further studies. For example, in our study, we did not find a significant correlation between the initial level of transformative inquiry skills and the final domain-related knowledge even if a higher level of skills should support students in knowledge acquisition. In the current study, we did not consider how students' regulative inquiry skills affect the inquiry and knowledge construction. Thus, this might also be an important factor that has to be studied further. Finally, testing the model in the context of other learning environments would be important.

Acknowledgments The SCY ECO mission was developed in the context of the SCY project, which was funded by the European Union (EU) under the Information and Communication Technologies theme of the 7th Framework Programme for R&D (grant agreement 212814). This document does not represent the opinion of the EU, and the EU is not responsible for any use that might be made of its content. We would like to acknowledge the SCY project members as well as teachers and students who participated in the study for their contributions.

References

1. Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology*, *103*, 1–18. doi:http://10.1037/a0021017
2. Altin, H., & Pedaste, M. (2013). Learning approaches to applying robotics in science education. *Journal of Baltic Science Education, 12*(3), 365–377.
3. De Jong, T., Weinberger, A., Girault, I., Kluge, A., Lazonder, A. W., Pedaste, M., Ludvigsen, S., Ney, M., Wasson, B., Wichmann, A., Geraedts, C., Giemza, A., Hovardas, A., Julien, R., van Joolingen, W. R., Lejeune, A., Manoli, C., Matteman, Y., Sarapuu, T., Verkade, A., Vold, V., Wanders, B., & Zacharia, Z. C. (2012). Using scenarios to design complex technology-enhanced learning environments. *Educational Technology Research & Development, 60*(5), 883–901.
4. Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and Quasi-experimental studies of inquiry-based science teaching. *Review of Educational Research*, *82*, 300–329. doi:http://10.3102/0034654312457206
5. Kori, K., Pedaste, M., Leijen, Ä., & Mäeots, M. (2014). Supporting reflection in technology-enhanced learning. *Educational Research Review, 11*, 45–55.
6. Mäeots, M., Pedaste, M., & Sarapuu, T. (2008). Transforming students' inquiry skills with computer-based simulations. In *Proceedings of the 8th IEEE international conference on advanced learning technologies* (pp. 938–942), 1–5 July 2008, Santander, Spain.
7. Mäeots, M., & Pedaste, M. (2014). The role of general inquiry knowledge in enhancing students' transformative inquiry processes in a web-based learning environment. *Journal of Baltic Science Education, 13*(1), 19–31.
8. OECD. (2013). *PISA 2012 results: What students know and can do—Student performance in mathematics, reading and science* (Vol. 1). Pisa: OECD Publishing. doi:http://dx.doi.org/10.1782/9789264291118-en
9. Pedaste, M., & Sarapuu, T. (2006). The factors influencing the outcome of solving story-problems in a web-based learning environment. *Interactive Learning Environments, 14*(2), 153–176.
10. Pedaste, M., & Sarapuu, T. (2006). Developing an effective support system for inquiry learning in a web-based environment. *Journal of Computer Assisted Learning, 22*(1), 47–62.
11. Pedaste, M., & Sarapuu, T. (2014). Design principles for support in developing students' transformative inquiry skills in web-based learning environments. *Interactive Learning Environments*, *22*(3), 309–325.
12. Pedaste, M., & Sarapuu, T. (2012). Uurimuslike oskuste kujundamine ja hindamine. In L. Koppel (Ed.), *Gümnaasiumi valdkonnaraamat loodusained. Bioloogia* (pp. 68–81). Tallinn: Riiklik Eksami- ja Kvalifikatsioonikeskus. in Estonian.
13. Pedaste, M., de Jong, T., Sarapuu, T., Piksööt, J., van Joolingen, W. R., & Giemza, A. (2013). Investigating ecosystems as a blended learning experience. *Science, 340*(6140), 1537–1538.
14. Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henrikson, H., & Hemmo, V. (2007). *Science education now: A renewed pedagogy for the future of Europe*. Brussels: European Commission: Directorate-General for Research.

Chapter 7
Five Powerful Ideas About Technology and Education

Andrea A. diSessa

7.1 Introduction

I aim here to distil my four decades of experience with technology and education into just a few ideas. Many of these ideas are absent from trends in popular discussion. Indeed, they sometimes run in the opposite direction. While discussing these ideas, I will point out some dissonances with "contemporary" thought, along with some more positive connection. All of these ideas are complex and subtle. So, interested readers should consult other sources, such as [6].

"The computer is a once in several centuries innovation." The first thing to take into account in looking for profound directions is that they will not be easy or short-term efforts. If they reach fruition, however, they will constitute grand cultural achievements, something our civilization may take pride in reaching.

7.2 Idea One: Computational Media and New Literacies

I think of computers as providing the basis for a new literacy. Literacies are big deals. They take many years, sometimes centuries, to spread widely and have their deepest effects. Textual literacy was clearly a big deal in the history of civilization. Many have studied the long paths to achieving widespread literacies, and no one doubts that they have had monumental transformative effects. Societies just work differently when they have both history and laws, which, for all practical purposes, cannot exist without textual literacy. Science, also, is essentially a literate pursuit.

A.A. diSessa (✉)
Graduate School of Education, University of California, Berkeley, USA
e-mail: disessa@berkeley.edu

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_7

Computers can offer easy-to-understand extensions to the power of textual literacy. Text is static in two senses: It does not change, and it does not respond interactively. In contrast, computational media are essentially dynamic and interactive. In expanding to include dynamics and interactions, they can engage intelligences (including our powerful spatial interpretive and imaginative capabilities) that are near-dormant with conventional literacy. These are not necessarily things that draw our attention. It is good to remember how boring (in a visual sense) conventional text is. And yet it made our modern world possible. New media's modes of helping us engage and extend ways of thinking that lie deep within us—intuitive, imagistic, and enactive thinking—are nearly untouched by text.

Conventional literacy sets a proper scale. A new literacy would be a grand cultural achievement. As such, it lies beyond "improving" our current ways of doing things. It will establish modes of thinking and interacting quite unlike what exist now. Realizing the promise will be challenging in many senses, including that, now, few people are conceptualizing or working toward these changes.

Computational media are expressively unlike text. Text is broadly applicable, but also imprecise and not easily adapted to specialized niches, like science or mathematics. A good comparison is to algebra as a literacy specially adapted to mathematics and science. It brings huge increments of precision and relevant expressiveness. Indeed, the history of algebra is instructive. While it began in the mid-eighteenth century, it was only in the twentieth century that algebra became a widespread literacy, essential for any technical trade or profession, expected to be learned by everyone. Algebra is particularly useful as a comparison because it engages modes of thought that "don't fit" easily in text (such as quantitative thinking), but which can be hugely expanded in efficiency, precision, and coverage, compared to text. Like text, algebra has become infrastructural in our educational system. Everyone is expected to pass through algebra on the way to college and beyond.

The expressive range of computational media is huge compared to algebra. Over the long haul, it will have a much bigger and broader effect, especially in technoscientific traditions. Computational media are also much easier to learn than algebra, and they extend into areas with which "ordinary folks" are interested and more competent than those approached by algebra: visual art, interactive story telling, "computer", and social game construction. In our work, students' affinity toward computational media for their own interests has been transparently evident.

The histories of other literacies follow patterns that may be repeated with computational media. Literacies develop slowly and often without notice. During development, few, if any, conceptualize the ultimate pervasiveness of the literacy, the depth of its possible influence on thinking, and its civilization-wide impact. Instead, literacies are first conceptualized as technical and encapsulated in exotic professions, such as "scribe." Literacies start as "one-way," something for many to consume (reading the thoughts of the master) but few will produce. Yet, one-way literacies, reading without writing, are in the end, impoverished.

There have been a few cultural resonances with true literacies in the history of technology and education. Early on (and maybe still today) people construe "literacy" in a denatured sense, as "shallow competence"—something with which someone ought to have some passing acquaintance, not something that is infrastructural to civilization and pervasive in school. In this regard, recent attention to programming and "computational thinking" is heartening. But the movement is in important ways ignorant of the larger possibilities and of the history of those aiming to make "writing" in computational media ("programming") a part of everyone's experience [9]. Advocates of learning programming also often do not see it as infrastructural, relevant to learning other things. The meme of vocationalization ("we need more professional programmers") obscures and marginalizes the big picture of new literacies.

7.3 Idea Two: Re-mediation

Thinking is symbiotically enhanced by all the external representations that humans have designed for their own intellectual purposes. Computational media will enable a myriad of external representation unrivalled in history, including: variations on text specialized for dynamic human interaction (social media); schematic and realistic (or real) still and dynamic pictures; all the specialized representations that have already extended familiar ones, such as nimbly adjustable extensions of "graphs" in exploratory data analysis. Among these representations, a special class are the means to specify action and interaction, the core innovations of computational media. We can call them "programming languages."

One fundamental fact about representations is that each has a delimited expressiveness. They "talk about" certain kinds of things well, and other things poorly. Algebra and calculus were fabulous facilitating representations for basic forms of physical dynamics, like Newton's laws. But, modern science has transcended the classical advantages of such representations. One doesn't predict the weather or explore fusion anymore by solving equations. One builds models using programming languages.

What will happen when computational representations come in contact with mathematics and science education? The easy prediction is that all the new sciences that have computation in their very core—data analysis, complex systems—will become newly feasible targets in school. The more difficult thing to understand is that all the old things that we once taught on the basis of text and static extensions will be changed almost unrecognizably when we "re-mediate" them with new representations.

One of the wonderful early experiments I organized with computational media was to teach sixth grade students high school physics (mechanics) in a yearlong class. The curriculum seemed wildly unrealistic to reviewers of our first proposal. In particular, they picked on the fact that we intended to teach vector formulations of the laws of mechanics. Vectors are now, indeed, a difficult part of high school curriculum; it seemed to reviewers outrageous that might be possible to do this in the sixth grade.

I adjusted our “expectations” to those of the reviewers, and we were funded. However, we did teach our students about vectors. We found it not only successful, but trivial. Vectors were, for these students, simply arrows on the screen that they made with a key-press and could adjust with the mouse. The meaning of vectors could be established, for example, with a one-line program that directed a graphical object to move with the velocity specified by a vector. Vectors, thus, became a “direct manipulation” interface to motion, and students could trivially see the effect of changing size or direction of velocity. Dynamic and interactive control over motion not only made the meaning of vector velocity (or acceleration) transparent, but it established a class of activities in which students enthusiastically engaged: making video games using vectors as “control” devices.

So, science and mathematics curricula can be liberated in unprecedented ways with computational media in terms of selection, ordering, and (see below) mode of student engagement. Explorations are just beginning; in the best of circumstances, there are decades of work to reform our educational system to optimally take advantage of re-mediation.

Sadly, this wonderful and dramatic task, exploring re-mediation in many or all school subjects, has hardly been noticed. The problem is worse that an unrecognized or unfunded possibility. The cultural trend toward a standards- and testing-based educational system could not be picking a worse time to legislate details of scope and sequence just when all the old assumptions need no longer apply. Without noticing it, our society may be freezing in constraints based on the affordances of old media and freezing out perhaps the best possibilities of re-mediated thinking and learning. Standards, just now, are dissonant with achieving the best with new-media literacies.

7.4 Idea Three: Engagement and Activity Structures

I am struck dumb as to why mathematics and science textbooks are so alike. You read, and then you do problems. Has this mode been established to be optimal?

While I am sure no one knows, and hardly anyone cares, I *might* imagine reading and problem solving may be the best way to learn science using old (static) media. Yet, I am convinced by logic and experience that we can do much, much better with new media.

Our sixth grade students responded to vectors as (1) easy-to-understand and, as important, (2) their pathway to things that truly interested them. They made games and simulations with them as if vectors were sticks and balls from the toy closet. Not only do some things become so much easier with computational media that they can be taught a half decade earlier, but students’ mode of engagement might also be radically changed.

Let me invent a short list of powerful modes of encounter for students that are greatly enhanced by computational media. First, in the case of our sixth grade students, much of their learning appeared to them to be game playing or game constructing. There is resonance in the zeitgeist. “Learning through games” is now at a pinnacle of interest among educators. (Much of this energy is unconcerned with conceptual re-mediation. So, educational effects may be mostly transient and hard won, unlike our shockingly easy accomplishments with re-mediated vectors.)

Another mode of engagement with content that is immensely facilitated by computational media is design. In our own work, this has taken two somewhat different forms. First, we had children design things that turned out to be proxies for scientific principles. In one case, we asked our sixth graders to design a simulation of dropping a ball [8]. What emerged, with little guidance, was one of Galileo’s great accomplishments, a conceptualization of gravitational fall, expressed in a simple program.

In another case we asked students to design a program to simulate a spaceship with a short-burst rocket engine [4]. This was a little trickier and at the high school level. But again, it seeded ideas with computational representations (vectors, unlike the dropped ball model). Students progressed to a good general representation of Newton’s conception of the effect of forces on motion in computational form (rather than using algebra or calculus).

The second mode in which we engaged design as a primary form for instruction is all the more pregnant with new possibilities provided by computational media. We asked students, from sixth grade to high school, to design representations suitable for scientific presentation of natural phenomena, from motion (again, in our sixth grade class), to representations of topographical features, to the design of aspects of computational representations of astronomical images. The wonderful synergy here is that, with the explosion of representational resources provided by computational media, we should cultivate students’ “meta-representational” capacities to design (and understand the design rationale behind given representations) far beyond what is now in the curriculum. A foundational scientific result of this work is that even children possess a remarkable foundation of ideas—and interest in—representational design [7].

Here, as with learning via games, the zeitgeist seems on the side of re-embedding content in design, or to value design, itself, as a new target of instruction. This is at least true in engineering, where, for example, the state of Massachusetts has mandated (engineering-based) design instruction in K-12. The trend is also vivid at the university level where there are strong currents to engage design much earlier in the curriculum.

A final “new” activity embedding for learning is research. In college-level physics and mathematic courses we designed, students did original research as freshmen, rather than learning by solving a set of artificial, and boring, problems, the universal mode for current algebra-based physics. Similarly, the mathematics we taught surpasses proof- and problem-based instruction, reaching independent student research. A proportion of this work (mostly mathematics) may be found in the textbook we produced [1].

Cultural resonance to research as an activity embedding for science instruction is tenuous. While there is a lot of research interest in activity-based science in K-12, anything resembling actual research (which entails uncertain outcomes) is rare in schools. There is, however, a fairly strong resonance with attempts to get undergraduates involved in research ("undergraduate research opportunities" programs). Yet, most of these make no contact whatsoever with core instruction in the sciences. An encouraging niche involves recruitment and retention programs that aim to make science a more attractive and meaningful endeavour for all students. Consider courses (such as Phys 98) listed for the excellent Compass Program at UC Berkeley: www.berkeleycompassproject.org.

7.5 Idea Four: Open Toolsets

The maturing of computational media will take a huge number of innovations, both technical and cultural, to realize a powerful, infrastructural literacy. This and the next section provide examples of such innovation. The first is mainly technical, a scheme for software design; the second is primarily cultural, a new social model for educational software production.

Media such as written text or programming languages are generic. Being generic is, in principle, a wonderful thing. Such media are expansive in their application and have the property of "learn once; use forever." That is, any expertise gained with the medium can be used again and again, in whatever context, for whatever mode, for whatever topics or purposes. For our experiments with computational media and new literacies, we developed an environment that is, in essence, a fusion of a programing language and a hypertext processor. The system is called Boxer, and our design intended to do at least as well as text and conventional graphics in terms of static media, but extended those capacities with constructible and reconstructible dynamic and interactive resources [3].

However, generic media have a critical shortcoming. The distance to specific application may sometimes be too large to suffer. There may be what some call the "Turing Tarpit," where everything is possible, but nothing is easy. A more apt description is that some things may be easy, but a few of them are exactly what you want to do.

To bridge the gap, we developed the idea of open toolsets. The idea is simple. A particular domain can be approached by building a set of tools that are adapted to the domain, and yet have the following properties: (1) They are built using the generic resources of the medium, hence anyone can, in principle, open them up to see how they work, or change them. (2) They appear in the system as generic objects. In Boxer, every object is a "box," so most tools are just boxes that can be cut, copied, pasted, or "opened" to reveal their insides, how they are constructed. (3) Tools may be easily combined using generic resources of the medium. In the simplest case, multiple tools can be used together simply by copying and pasting them together in the same place. In more complex cases, tools can be programmed "from the outside" by sending them messages that are nothing but programming commands. Or, gestures can be used to interconnect tools, such as "wiring" them together in the way that electronic devices are constructed by wiring together components.

The vectors mentioned earlier are a very simple Boxer open toolset. Vectors are ordinary Boxer graphical boxes that show a vector as an arrow and allow one to drag the vector's end-point around with a mouse. To manipulate vectors with programs, we also added commands to the language, in the usual Boxer way, that allowed simple expressions to, for example, add vectors as one conventionally adds numbers. Finally, we added other simple commands to allow vectors to interact with generic graphics boxes, for example, commanding a graphical object to move as a vector indicates—displacing in the direction and with the magnitude of the vector. Moving with the speed indicated by a vector is a one-line program using these resources.

Another very successful toolset that we built was designed to allow anyone, curriculum developers, teachers, or students to play with and build constructions that do image processing. Our main application was to astronomy, in particular processing images of the heavens to allow analysis of stars, planets, and galaxies, just as astronomers do. [2] explains elements of this toolkit and richly describes the uses that both we and students made of the toolkit. For our part, we (as ersatz curriculum developers and teachers) were able to build, very quickly and on the fly, exercises and activities for students: (a) to explore image processing in general, (b) to use image processing to aid in discovering and exploring visual phenomena in general, and (c) to conduct astronomical investigations using images from telescopes. Constructing an exercise or exploratory microworld for students was often a matter of an hour or so of work, using our toolset, and it seldom required as much as a day of work.

The flexibility of this toolset also allowed students to move off on their own to explore or play with a variety of things that were of interest to them. One student, for example, used some of the tools in the image processing tool set to explore the construction of beautiful palettes of colors with which to process images for aesthetic effect, like Photoshop or Instagram filters.

Other toolsets that we designed [5] included some to explore evolution, plant growth, ecological processes (population dynamics), and databases to allow flexible querying of relatively large data sets, or even just to store useful data for menial purposes. We even built a toolset for easily constructing specialized tools for the analysis of video data in our own research.

In short, open toolsets provide resources specialized to various domains and educational purposes, but they do not restrict developers, teachers, or students in their own use of those tools.

7.6 Idea Five: The LaDDER Model

Literacies are ideological. They embody—or at least uses of them embody—orientations that are characteristic of communities or cultures. For example, the Internet in most people's eyes embodies openness and democratic principles. Similarly, the kind of media and literacies that my group has espoused are strongly democratic.

We want everyone to have access and capability to use all the resources of computational media. Especially with technology, power and capability tend to reside at the "top," and narrowly in technically adept subcultures.

Figure 7.1 illustrates a mode of creating software with which we have experimented. It is called Layered Distributed Development of Educational Resources (LaDDER). The point is to push competence and capacity toward the lower, traditionally less technologically privileged levels. In this figure we stop with "teachers." In general, we most certainly would want to include students.

In Fig. 7.1, problems or gaps in capacity appear as black dots. Those problems are percolated upward (upward arrows) until they can be solved. However, the best solutions are not solutions, per se; they should be new resources or know-how (gray ovals) that can be percolated back down the layers (downward arrows) so that, ideally, everyone can solve not only the problem that initiated the process, but related problems as well.

We experimented with the LaDDER model in collaboration with a school district in Florida. Originally, a technologically experienced and university based mathematics and science specialist came to us asking for a little tool to create colored number charts (for example, coloring all the multiples of 2 in blue on a 10x10 chart of the numbers from 1 to 100). This is a familiar form in traditional textual (printed) form around the world. But this specialist believed that a flexible, interactive form could achieve far more than traditional forms.

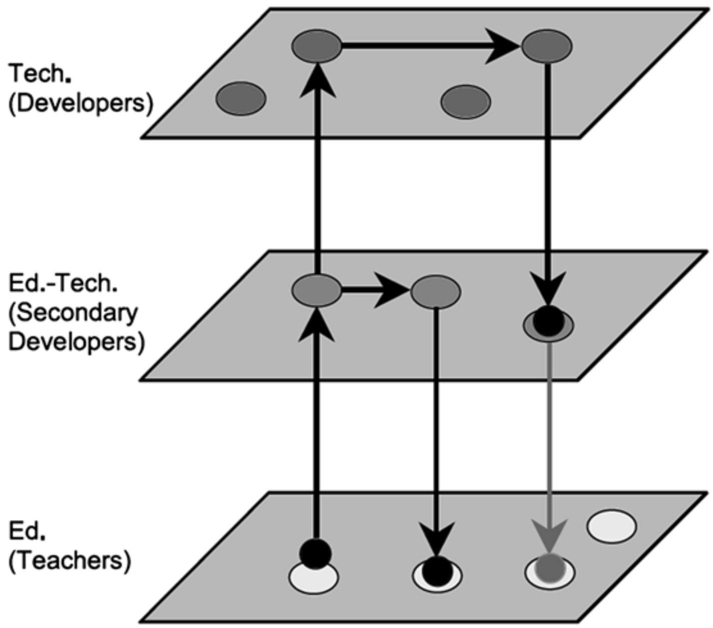


Fig. 7.1 The LaDDER model

Over the next few years, working closely with local teachers, this specialist developed an extensive curriculum for elementary math on the basis of the original toolset and extensions. Each summer, he would return to Berkeley for a visit with a wish list of items, some from him, some from his teachers. For example, he wanted to open aesthetic avenues, not just mathematical ones, so he wanted the simple capability *not* to display numbers in the colored charts. We obliged, but also suggested that he use some of the color and palette generating tools that we originally developed for image processing. His collaborating teachers wanted to change the interactivity of the chart so that students' clicking on the chart could be interpreted as the answers to questions in little interactive quizzes they produced for students. We obliged with "hooks" so that interaction could be modified in general and at will.

Eventually, the curriculum was extensively tested in a large scale, random assignment study [10]. It was impressively successful, and we believe (but cannot prove) that a part of the success was building deep attachments to classroom practice via involving both this math specialist and teachers in the creation of suitable software. The educators did the work, and we just helped them with resources they could use to do the things they wanted to do.

7.7 Conclusion

The promises of technology in education are grand. But, realizing the best will be a subtle, long-term enterprise, far beyond—and different from—what many expect. What draws people's attention to technology is often simply not on the paths to the best that we can imagine. This note presents some of the best ideas I have collected and developed in my career as an educational technologist. We should think at the level of new media and computational literacies. We should exploit re-mediation to re-organize the curricular landscape. We can now re-embed learning in activities that students find more personally meaningful, such as design and research. Finally, we should explore flexible new forms of software and social organizations for producing them.

References

1. Abelson, H., & diSessa, A. A. (1981). *Turtle geometry: The computer as a medium for exploring mathematics*. Cambridge, MA: MIT Press.
2. Azevedo, F. (2006). Personal excursions: Investigating the dynamics of student engagement. *International Journal of Computers for Mathematical Learning, 11*(1), 57–98.
3. diSessa, A., Abelson, H., & Ploger, D. (1991). An overview of boxer. *Journal of Mathematical Behavior, 10*(1), 3–15.

4. diSessa, A. (1995). Designing Newton's Laws: Patterns of social and representational feedback in a learning task. In R.-J. Beun, M. Baker, & M. Reiner (Eds.), *Dialogue and interaction: Modeling interaction in intelligent tutoring systems* (pp. 105–122). Berlin: Springer.
5. diSessa A. (1997). Open toolsets: New ends and new means in learning mathematics and science with computers. In E. Pehkonen (Ed.), *Proceedings of the 21st conference of the international group for the psychology of mathematics education* (Vol. 1, pp. 47–62). Lahti, Finland: PME 21.
6. diSessa, A. (2001). *Changing minds: Computers, learning, and literacy*. Cambridge, MA: MIT Press.
7. diSessa, A. (2004). Meta-representation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293–331.
8. diSessa, A. (2008). Can students re-invent fundamental scientific principles?: Evaluating the promise of new-media literacies. In T. Willoughby & E. Wood (Eds.), *Children's learning in a digital world* (pp. 218–248). Oxford, UK: Blackwell Publishing.
9. Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational Researcher, 42*(1), 38–43.
10. Ploger, D., & Hecht, S. (2009). Enhancing children's conceptual understanding of mathematics through chartworld software. *Journal of Research in Childhood Education, 23*(3), 267–277.

Chapter 8
Analysis of an Inquiry-Based Design Process for the Construction of Computer-Based Educational Tools: The Paradigm of a Secondary Development Tool Negotiating Scientific Concepts

Zacharoula Smyrnaiou, Evangelia Petropoulou, Maria Margoudi, and Ioannis Kostikas

8.1 Introduction

The influx of a number of open educational software in education has enriched or even "burdened" the role of the teacher with the one of the designer of targeted tools for the negotiation of specific cognitive concepts, especially in cases which seem to be problematic in engaging students in meaningful understanding or as an attempt to eliminate any misunderstandings students may have [4, 12]. The genesis of learning artifacts should be informed and guided by modern pedagogical theories and practices. In addition, their conceptualization and development requires an in-depth understanding of the cognitive subject under negotiation which, in turn, is also perceived to determine the selection of the instrumental "generator" [22, 23]. Although many studies have been conducted on the use and the targeted selection of effective educational tools, there is a lack of information concerning the design process followed by each designer-teacher as well as the analysis of the influences governing his/her decisions – both as a whole and partially – in the design process.

The present study based on the methodology of design-based research [5] aims to analyze step by step the creative design course of a candidate teacher of physics, in order to achieve a cognitive mapping of the conceptual perceptions, in the way

Z. Smyrnaiou (✉)
University of Athens, National and Kapodistrian, Zografou, Greece
e-mail: zsmyrnaiou@ppp.uoa.gr

E. Petropoulou• M. Margoudi • I. Kostikas
Educational Technology Lab, School of Philosophy, Faculty of Philosophy, Pedagogy and Psychology, Department of Pedagogy, National Kapodistrian University of Athens, Room 545 and 540, University Campus, Ilisia, 15784 Athens, Greece
e-mail: liana.petropoulou@gmail.com; maria.margoudi@gmail.com; ikostikas@gmail.com

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_8

they occur, during the design process. This, frame by frame, in the form of snapshots, cognitive mapping will be examined and analyzed through the dynamic pairs and interconnections of knowledge aspects (content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK)/TPACK) as well as the Cognitive schematization frame (COSC). Our detailed study based on cross-analysis aims at recording the sequence and temporal specifications of the influences on the designer-teacher, which determine the way he interacts with the tool, as well as his decisions in terms of semiotic projection and representation of scientific concepts. By tracking the designer's decisions on the creation of a tool, informed by the inquiry-based scientific approach, we perceive his own conscious and subconscious alignment with the inquiry-based process. In his effort to design and implement on the tool hypothesis testing and experimentation activities in the form of simulated structures, the designer seems to undergo the same inquiry process in combining the cognitive and TPACK principles as he interacts with the tool.

Our main goal is to determine to what degree the design process can be represented in the form of a pattern which could act as a point of reference and verification in a design process. The difficulty of the task lies in the fact that it examines nonlinear interconnected forces while aiming at their linear imprinting from the beginning of the genesis of the idea (also considering whether the design project, at the very beginning, is viewed holistically or analytically) and in the fact that it focuses, during the analytical examination, on the study of isolated constructs – cognitive and representational – which are multi-dynamic products.

We hope the findings of our study will contribute to the exposure of a "guide" to which the designer-teacher would refer in order to verify the effectiveness of his artifacts. Like a contractor, while examining the crack in a wall, is mentally challenged by a multitude of factors both causal and deterministic of future behaviour of the wall as well as by the fundamental principles of his subject content in order to follow a specific and temporal succession as to the repair process and the selection of adequate equipment, likewise we want to highlight a rational process which will help us map out an effective design course towards the realization of an educationally extensive (with respect to the triptych of pedagogical, technological and cognitive framework) construct. Although this nascent taxonomy may not be possible to map, given the interference of the human factor that is on its own an infinite source of new ideas, we believe that our contribution in setting some principle criteria to guide the design process will be useful to teachers involved in the design of educational artifacts.

8.2 Related Work

The advent of a new generation of educational tools, during the last decade, especially those targeted at STEM sciences, aims not only to an interactive conversation between the user and the tool while the user is engaged in solving problem activities through simulation representations but also to the design itself of cognitive activities by manipulating autonomous components as boundary objects of negotiation [3, 17]. Whether the theoretical framework of artifacts is based on the principles of “perception based design” or on the “action-based design” [1] common factors are identified which contribute to the design of learning activities targeted to engage pupils in the re-discovery of fundamental cognitive concepts. Our goal, of course, is not to address design practice as a procedure of exhaustive or standardized design models but to create a multiple-entry framework which may reflect and unravel a dialogic argumentation and the designer’s individual rationale [1, 7].

In the present study, based on the framework of TPACK [15], the design mapping is perceived through the multiple interactions raised by the threefold dynamic of the parameters of knowledge: content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK). These three dynamic components which define an effective learning process do not operate independently but in close interaction and correlation among each other. As a result, they develop multiple systemic extensions and multidimensional approaches, while co-forming the teaching of a subject. As shown in the figure below (Fig. 8.1), from the intersections of the circles of content, pedagogy and technology, three new forms of knowledge are formulated: (a) the pedagogical content knowledge (PCK), which constitutes the ability to

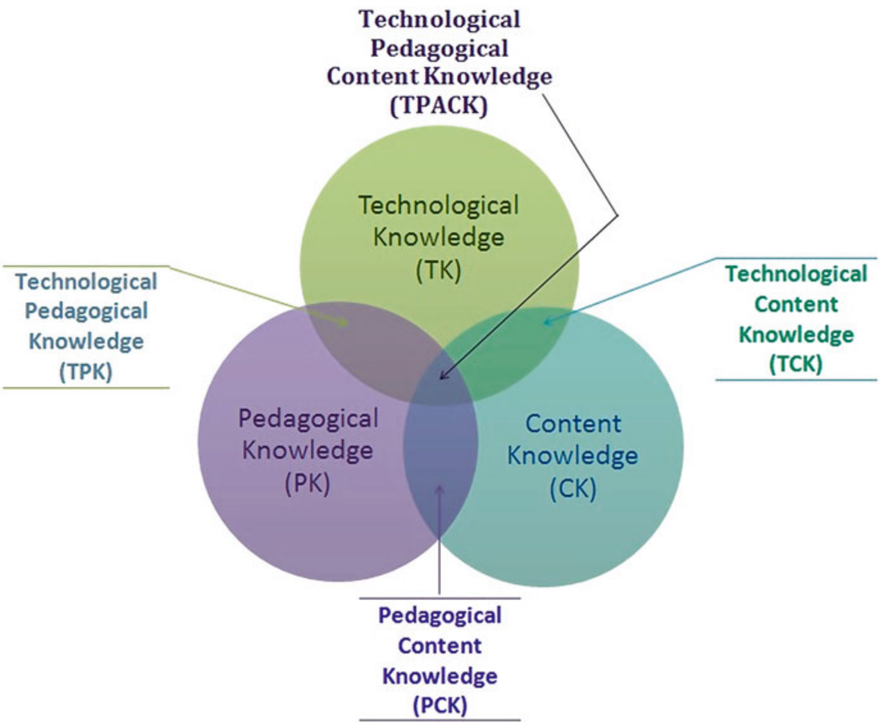


Fig. 8.1 The TPACK model and the parameters of knowledge as adapted by Koehler & Mishra’s figure [15]

transform the educational material with the application of appropriate educational methods and teaching strategies, taking into account students' prior knowledge and epistemological theories [14], (b) the technological content knowledge (TCK), which is based on the knowledge of the interconnection between technology and content, in other words, how they affect and also obstruct one another or the way in which the content dictates and/or pushes in changes in technology and vice versa [13, 15], and (c) the technological pedagogical knowledge (TPC), which refers to the development of skills deriving from the effective integration of technology in the teaching practice, with a view to accomplishing an effective learning process [13, 14].

Artifacts which are perceived as 'entities with substance' after human intervention [19] should be explored in their dual dimension, as environments of work and reflection as well as final outputs governed by their own dynamic, reshaping properties. The constructionist approach of learning environments based on either exploratory learning or modeling of scientific concepts [6, 22, 24, 25] provides the basis for deep access to cognitive areas which emerge according to the designer's reaction and personal perception while interacting with these environments; constructing this way his/her own operational invariants (concepts-in-action and theorems-in-action) and meaningful representations [27, 29]. So, according to the concept of instrumental genesis, two functions are performed simultaneously: one function relates to the evolution of the artifacts themselves as the user's activity unfolds, and the other concerns the construction of systems that will facilitate the utilization of the artifacts. Both functions contribute to the realization of the tool through a continuous and interactive relationship between the bipolar field of 'instrumentation', i.e., the orientation towards the subject (subject-oriented), and 'instrumentilization', i.e., the orientation towards the artifact (artifact-oriented) [2]. During the designer's engagement with the creative adaptation and identification of the tool, – which functions as a mediator of the action and the targeted activity [9, 19] – a dynamic dialogue is established, leading to the selection of rational and feasible design steps. These design steps are informed by a number of issues, ranging from techno-pedagogical ones – such as the projection of physical laws and scientific properties on simulated representations, considering the aesthetic result and the operability of the environment – to the issue of the potential for evolution and extensibility of cognitive concepts in order for new cognitive schemas to be revealed [20]. By adopting a cognitive schema, with the ultimate aim of producing a final output, the designer juxtaposes his own system of available resources to the diversity of each instrumental environment in order to achieve a productive adaptation, which in turn contributes to the enrichment of the system resources. Naturally, it is the designer's conceptualization of the artifact that triggers the design process and provokes the transformation of a mentally primitive prototype – which is subject to multiple modifications with the intervention of mediator symbolic forms and representational devices [21] during the visibilization process – to a well-grounded and sound construct.

The artifact is designed to promote the development of transformative inquiry skills, since it aims to engage students in hypothesis and experimentation actions that need to be followed step-by-step in order to result in the discovery of new relationships [18]. While the designer is engaged in the design process, he applies himself inquiry skills in his effort to manipulate the visualization of the research questions, their experimental procedure, analysis and interpretation [16]. With the application of the inquiry skills, the designer's reflective mechanisms are triggered [16] and enable the evaluation of the efficiency of the artifact. In this research study, modelling supported by inquiry-based approach [26] denotes the way the designer envisions his students to manipulate the tool but also projects the conceptual process he undergoes while engaged in the design process.

8.3 Study Design and Methodology

This research study is based on the research methodology of design-based research [5], which includes the design of tools and tasks in the specific context of their utilization in order to achieve understanding and clarification of the relations and mechanisms of connection between theory, designed artifacts and practice, with the objective of creating "usable knowledge" [28]. The validity and reliability of the research was ensured by the application of the cross analysis technique since it was conducted by three researchers, in order to model and evaluate the evolution of the design process of an artifact negotiating scientific concepts in the digital environment of E-slate (http://etl.ppp.uoa.gr/_content/download/index_download_en.htm).

8.3.1 Research Framework and Design

The research was conducted in the Laboratory of Educational Technology, University of Athens, and lasted about 3 weeks, during which 27 microworlds were produced all of which negotiating the same cognitive module – Kinematics and Dynamics of Physics – and more specifically a control of the conditions for comet collision with the planet earth. Throughout the course of the design process, the designer – undergraduate of the Physics Department of the Faculty of Sciences, National and Kapodistrian University of Athens – was supported by a researcher for technical rather than cognitive issues through a Wiki platform.

8.3.2 Data Collection Procedure and Reliability of the Research

The data which were collected by three researchers, through the application of the technique of cross analysis – as a type of reliability control, on the basis of reproducibility – were coded and analyzed in order to address our research study concerning the temporal succession as well as the frame-by-frame recording of the alternation between concepts of the TPACK framework and cognitive schemes which occur during the design process. Each of the 27 artifacts which were designed constituted a unit of analysis on the basis of recording the entire process via hypercam. All the microworlds were grouped and examined on the basis of their time sequence in three temporal stages (initial stage, middle stage, completion stage), which enabled us to register and examine the designer's sequential activation through the TPACK and COSC filters. The research data include records and conversations from the Wiki environment and an interview with the student-designer in order to provide additional information and clarification on his rationale regarding the chronological priority he sets. During the design process, we track and follow the designer's cognitive process, while dealing with the projection of the cognitive content and manipulating the technical functions (quantitative and qualitative) of the computing environment, as well as his interpretation for the specific transitions from one procedural level to another.

8.4 Analysis and Results

8.4.1 Cross Analysis Snapshots of the Procedural Design Genesis

During this design process, the E-SLATE platform is exploited, which is a source of pre-manufactured educational software, as well as an authoring system and a system of secondary software development. Analytically, the design experimentation in the initial microworlds involves adaptations of existing elements from the template microworld – D-Stage – which is oriented towards the negotiation of scientific concepts. However, the initial microworlds evolve with entries of original orders into their codes as well as additions of components which constitute a figment of the inquiry-based interaction between the designer's cognitive resources and the technical affordances and response of the open authoring environment. For the sake of economy, we have decided to present the analysis of three microworlds; each one typical of the temporal stage to which they belong.

1st Microworld: 1J.mwd From the very first microworld (Fig. 8.2), which obviously belongs to the initial stage of artifact production, it appears that the designer has already captured holistically rather than analytically the artifact by constructing

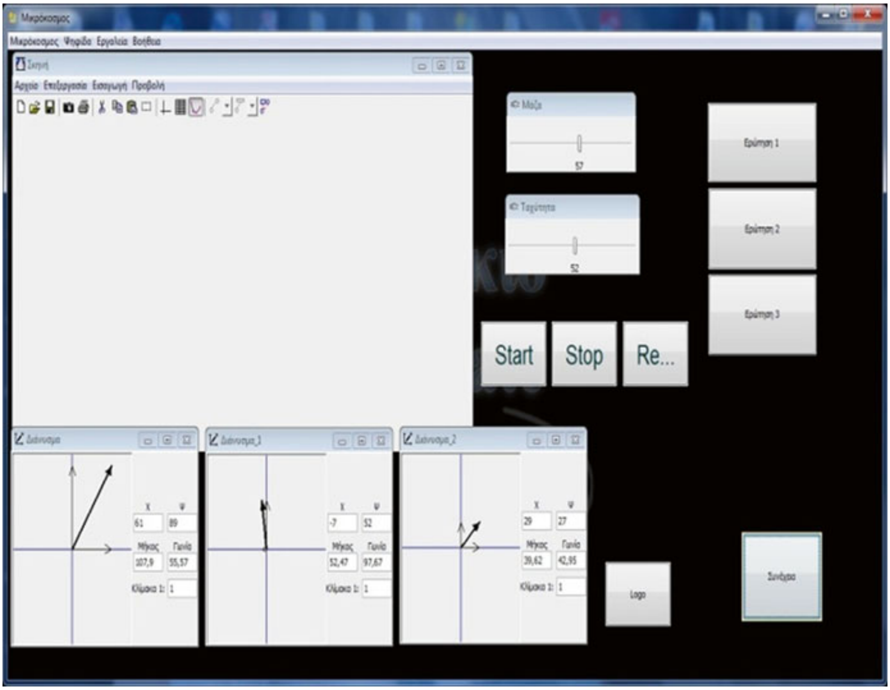


Fig. 8.2 The initial microworld based on the template microworld, D-stage

the element of distinction between two separate levels of the game, which reveals his general plan for the completion of the microworld. The selection of the depicted components ('Speed' and 'Mass' Sliders, scene) is declarative of the cognitive concepts that the designer attempts to project. Moreover, on a technical level, on the component scene, which is the central element of the microworld, it is attempted a simulated representation of the interventions and the modifications undertaken in the remaining components of the microworld which are closely related to it. On a cognitive level, the scene will constitute the panel for the meaningful interpretation of the moves that will be made by the user during his engagement with the tool. At this stage of manufacturing, most of the components of the microworld remain empty, as the concept of virtual collision of two bodies (comet and earth) still remains in the mind of the designer. In terms of personal interventions on the part of the designer, there have not been any technical changes in the form of code input or connection of existing components, since the designer, at this point, is mainly concerned with the selection of components suitable for the implementation of his original plan. Moreover, indicative of the designer's initial reflection is the addition of the button components "Start", "Stop", "Reset", "Continue" and "Question", which project the sequence of the designer's conceptual plan which seems to address specific learning objectives and pedagogical methods.

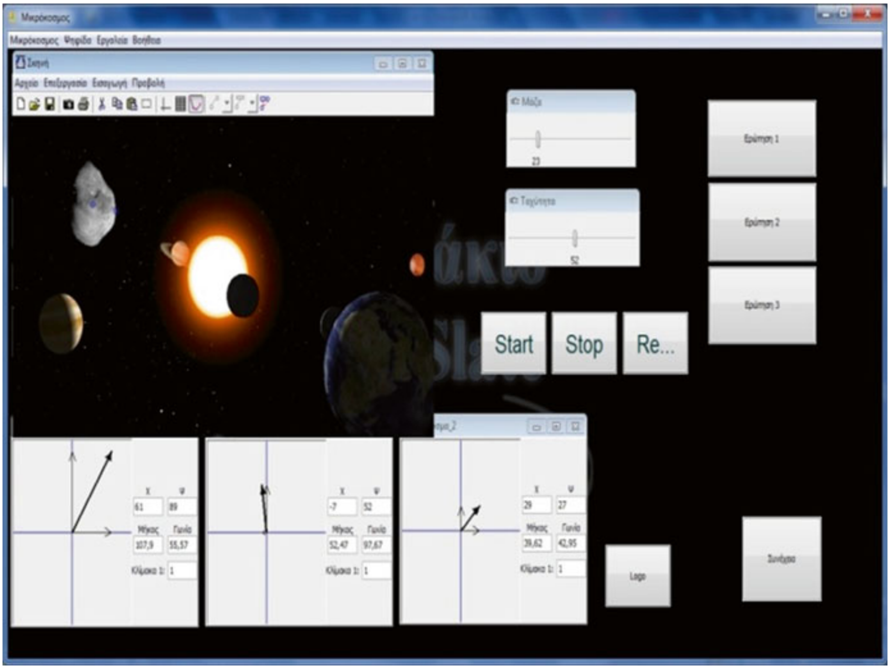


Fig. 8.3 Projection of the designer's reflection process

7th Microworld: 7J.mwd Through this microworld (Fig. 8.3), the designer's wavering, regarding the definition of the slider condition, is displayed. The 7th in the row microworld, which belongs to the middle stage of artifact production, reflects the capturing of the reflective design process, which involves the designer in an in-depth reflection regarding the cognitive subject. It is evident that this reflective process is triggered by the combination of virtual projection – as a result of the initial design concept and its modification due to the technical potential provided by the environment for experimentation – feedback and spatial intervention in defining conditions. At this stage, the designer proceeds to the use of programming language by inserting code into the 'Logo' component, concerning the behaviour of the 'Comet' component as well as the customization of the value of forces displayed on the 'Mass' and 'Speed' sliders.

25th Microworld: 16.61J.mwd With the initiation of the 25th Microworld, all the components are now visible. Regarding the Microworld's degree of functionality, at this point, it is well constructed performing the programmed functions with the sole exception of the turtle-tracks which are still under negotiation. In this phase, in order for the designer to finalize the efficient integration of the cognitive content and to determine the inquiry-based process that should be applied for its negotiation (with respect to determining how and what will be imprinted on the turtle-tracks), he resorts to a holistic view of his artifact. At this design stage (completion stage), the designer selects the dual role of designer-user in order to follow the entire process of operation and management of the environment he has created. The designer by assuming this dual role examines the efficiency of the environment in terms of cognitive, representational and pedagogical appropriateness and reflects on the data display on the turtle-tracks.

8.4.2 Results

The data collected from the vertical and horizontal approach of the 27 artifacts microworlds were subsequently coded in order to arrive at quantitative findings relating to our research questions. In our analysis, each microworld constitutes a unit of analysis, which is examined each time on the basis of the new modifications-interventions it undergoes and not holistically in conjunction with previous changes that have occurred. The microworlds were grouped and examined on the basis of their time sequence in three temporal stages (initial stage, middle stage, completion stage). As illustrated in Fig. 8.4, there is a different activation and dynamic during

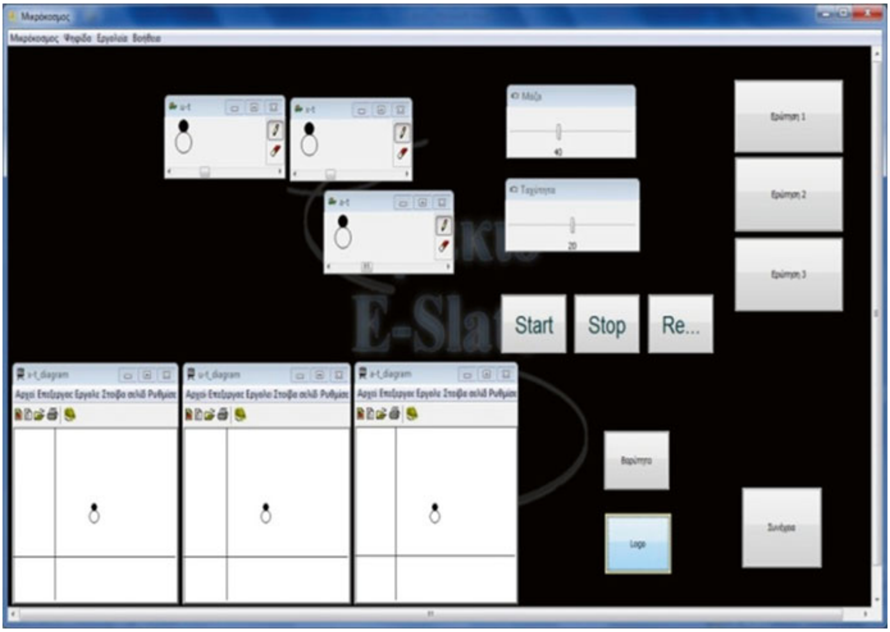


Fig. 8.4 Projection of the designer's reflection on the data display on the turtle-tracks

the alternation among the frames of analysis in the design process, in relation to the temporal stage of the design. At the initial stage, the designer shows intense activity on the axis of technological content knowledge (TCK), in his attempt to adjust the way in which the content dictates and/or forces the changes in technology and vice versa. In addition, he seems to be strongly engaged in a mental process concerning the elaboration of cognitive concepts. Naturally, this mental process is informed by the instrument and deals with the construction of the appropriate operational invariants in relation to the negotiated scientific concepts. In contrast, at the initial stage, the designer seems to take less account of the technological pedagogical knowledge (TPK). Therefore, the designer sets a prioritization hierarchy by dealing first with the projection of content and its related cognitive schemas on the tool and leaving the application of pedagogical techniques, for a later consideration. At the middle stage, the designer, having accustomed himself to the potential of the digital tool for the projection of the content knowledge, mainly focuses on the improvement of the projection of the cognitive schemas. At this stage, he seems to dynamically interact with the tool either by attempting to exploit its functions or by paraphrasing the cognitive concepts in order to make them visible in this computing environment. This is also the stage for the integration of pedagogical techniques which engages the designer in an inquiry-based process in his effort to determine the pedagogically informed channelling of the content on the computational environment. The user's design evolution, at this stage, is reflected from his low involvement with the axis of technological content knowledge which has been more thoroughly dealt with at the initial stage. The designer has now passed from the stage of guidance by the tool and dictation by the content knowledge to the stage of personal cognitive intervention and creativity. Finally, during the stage of completion of the design process, the designer mainly deals with the projection of cognitive schemas, reflecting his increasing cognitive involvement. Towards the finalization of the design process, the designer also considers and examines the efficient realization of the content projection and application of pedagogical knowledge, in the context of their interaction with the tool (Fig. 8.5).

8.5 Conclusions

The designer's cognitive and creative background along with the authoring template will trigger the visibilization process of the artifact and its successful completion will be achieved through the intervention of symbolic forms. Until the realization of the final microworld, the course followed by the designer proceeds from simpler cognitive and technological steps, such as the adjustments of readymade items from other microworlds, to more sophisticated interventions, like the entries of original orders and the additions of components. The designer followed patterns and used invariant operations for the design of the microworlds which allowed him to proceed with further modifications and improvements. The design of the microworlds on paper had preceded the design in the computing environment of E-slate, making

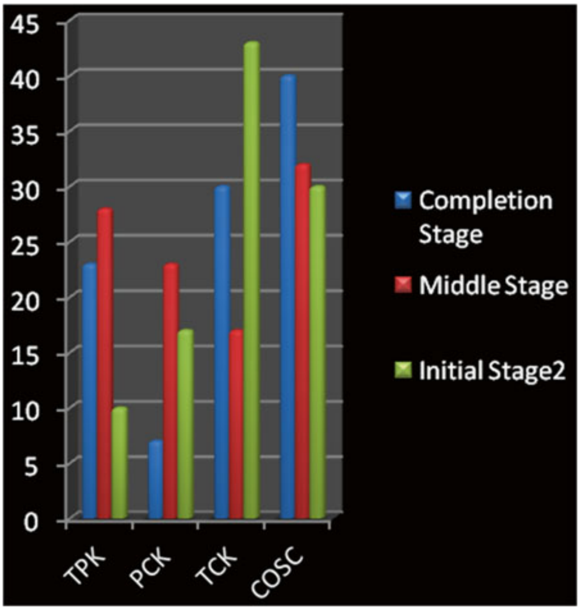


Fig. 8.5 Schematic representation of the analysis categories based on temporal stages

evident the additional value of the computing environment which allowed the designer's intense interaction with the artifact and enabled modifications. This dynamic of the computational environment facilitates an in-depth reflection on the cognitive concepts, as it ensures their successful projection on the computing environment. The designer's application of the inquiry-based approach not only facilitates and triggers a reflective evaluation of the artifact but also enables him to submit himself to the inquiry process he aims at his students. By assuming the same role with his students and undergoing similar cognitive processes, the designer manages to configure a most scientifically guided and learning efficient construct.

From the recording of the design activities, it becomes apparent that the designer's decisions establish a framework of priorities which are clearly classified into levels of difficulty and accessibility – initially performed in a superficial and managerial manner, and progressively becoming more penetrating and interventional. The designer's attained mastery and efficient handling of the environment will enable him to conceptualize the restructuring of the cognitive content in terms of tool affordances and functionalities. Afterwards, the designer, by processing all the axes (content, pedagogical and technological knowledge and the cognitive schematization), manages to incorporate and effectively manipulate all the parameters – tool, cognitive content, pedagogical implementation. The whole process denotes a parallel and multi-dimensional focus which requires high order skills. This effort to include and creatively harmonize all the parameters will continue till the end, until the designer senses their effective delivery.

8.6 Future Work

Although the findings of this research study helped us to reach some primary conclusions regarding the modeling of the design process, further investigation is required with a larger number of design artifacts to enable us to make specific generalizations. As an extension of our research we would also like to thoroughly examine the transformative and regulative inquiry skills that the designer-teacher applies while engaged in the design process. Such data would enable us to shed light on the designer-teacher's scientific profile, acquired skills and cognitive resources. In addition, it is within our research interest to conduct a study with an aim to observe and examine the users' inquiry-based manipulation of the produced microworlds (as semi-complete boundary objects) in order to track the potential of the tool in terms of extensibility and enhancement of personal creativity.

Furthermore, we believe that further research is required in order to determine if and how the design process varies depending on the designer-teacher's professional expertise and cognitive subject. Although according to Gardner [10, 11], each subject content is governed by its own dynamic which shapes and updates the process of knowledge development, methods, objective and representation, it would be of great importance to examine the possibility of a common design mapping structure, based on the fundamental development processes (description, selection, representation, inference, synthesis, verification) informed by each subject content [8]. In the case of a common design mapping structure for all subject contents, further research should be conducted on the responsive nature of all kinds of open environments – defining similarities and differences – in terms of construction or deconstruction of representational models, dynamic handling of physical objects, data and information management. Finally, once our questions have been explored and answered we would like to formulate an AI tool which would automate every designer-teacher's design intervention. However, in all cases we can assume that by having teachers explore the unknown aspects of the design process, unknown aspects of the way students learn are also highlighted. Towards this aim, the deriving data are of great value and should be taken into consideration by the teachers in order to embed those findings in the tool they design to address their students' needs.

References

1. Abrahamson, D. (2013). Toward a taxonomy of design genres: fostering mathematical insight via perception-based and action-based experiences. In J. P. Hourcade, E. A. Miller & A. Egeland (Eds.), *Proceedings of the 12th Annual Interaction Design and Children Conference (IDC 2013)* (Vol. "Full Papers," pp. 218–227). New York: The New School & Sesame Workshop.
2. Béguin, P., & Rabardel, P. (2000). Designing for instrument-mediated activity. *Scandinavian Journal of Information Systems, 12*(1), 173–190.

3. Blikstein, P. (2013). *Gears of our childhood: constructionist toolkits, robotics, and physical computing, past and future*. In Proceedings of the 12th international conference on interaction design and children, ACM (2013), pp. 173–182.
4. Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience and school*. Washington, DC: National Research Council, Committee on Developments in the Science of Learning.
5. Cobb, P., Confrey, J., diSessa, A., Lehrer, P., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13.
6. De Jong, T. (2005). The guided discovery principle in multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 215–229). Cambridge: Cambridge University Press.
7. diSessa, A. A. (2000). *Changing minds: Computers, learning and literacy*. Cambridge, MA: The MIT Press.
8. Donald, J. G. (2002). *Learning to think: Disciplinary perspectives*. San Francisco: Jossey Bass.
9. Engeström, Y. (1990). When is a tool? Multiple meanings of artifacts in human activity. In Y. Engeström (Ed.), *Learning, working and imagining: Twelve studies in activity theory*. Helsinki: Orienta-Konsultit.
10. Gardner, H. (2005). *Five minds for the future*. Harvard, MA: Harvard Business School Press.
11. Gardner, H. (2000). *The disciplined mind: Beyond facts and standardized tests, the k-12 education that every child deserves*. New York: Penguin Putnam.
12. Halloun, I. A. (2007). Model-centered, assessment-guided learning and instruction in science. In *Proceedings of the 5th Pan-hellenic conference 'science teaching and new technologies in education'*, 5 (A).
13. Koehler, M. J. (2011). *Technological pedagogical and content knowledge*. http://www.tpck.org/. Visited 2 March 2014.
14. Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70.
15. Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. In Committee on Innovation and Technology (Ed.), *The handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 3–29). Mahwah: Lawrence Erlbaum Associates.
16. Kori, K., Mäeots, M., & Pedaste, M. (2014). Guided reflection to support quality of reflection and inquiry in Web-based learning. *Procedia – Social and Behavioral Sciences, 112*, 242–251.
17. Kynigos, C. (2007). Half-Baked logo microworlds as boundary objects in integrated design. *Informatics in Education, 6*(2), 335–358.
18. Mäeots, M., Pedaste, M., & Sarapuu, T. (2009). Developing students' transformative and regulative inquiry skills in a computer-based simulation. In *Proceedings of the eighth IASTED international conference web-based education*. Anaheim: ACTA Press.
19. Rabardel, P. (1995). *Les hommes et la technologie, une approche cognitive des instruments contemporains*. Paris: Armand Colin.
20. Resnick, M., Berg, R., & Eisenberg, M. (2000). Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. *The Journal of the Learning Sciences, 9*(1), 7–30.
21. Sherin, B. L. (1996). The symbolic basis of physical intuition. *A study of two symbol systems in Physics Instruction.* A dissertation submitted for the degree of Doctor of Philosophy in Science and Mathematics Education in the University of California, Berkeley.
22. Smyrnaiou, Z., & Weil-Barais, A. (2005). Évaluation cognitive d'un logiciel de modélisation auprès d'élèves de collège. *Didaskalia, 27*, 133–149.
23. Smyrnaiou, Z., Komis, V., Dimitracopoulou, A. (2006). *Contribution à l'étude des raisonnements des élèves sur les acides et bases avec l'utilisation de vidéo, des objets reels et de logiciel éducatif*. Paper presented at 8[e] Biennale Internationale de l'éducation et de la formation: débats sur les recherches et les innovations, Lyon, France.

24. Smyrnaiou, Z., & Dimitracopoulou, A. (2007). Inquiry learning using a technology-based learning environment. In C. Constantinou & Z. Zacharia (Ed.), *Computer based learning in sciences*. Proceedings of 8th international conference on computer based learning (pp. 90–100). Heraklion, Crete.
25. Smyrnaiou, Z., Moustaki, F., & Kynigos, C. (2011). METAFORA learning approach processes contributing to students' meaning generation in science learning. In D. Gouscos & M. Meimaris (Eds.), *Proceedings of the 5th European conference on games based learning (ECGBL)* (pp. 657–664). Athens: Academic Publishing Limited.
26. Smyrnaiou, Z., Foteini, M., & Kynigos, C. (2012). Students' constructionist game modelling activities as part of inquiry learning processes. *Electronic Journal of e-Learning, 10*(2), 235–248.
27. Smyrnaiou, Z., & Moustaki, F. (2012). Creating motion models by manipulating parameters that correspond to scientific conventions. In C. Kynigos, J. E. Clayson, & N. Yiannoutsou (Eds.), *Proceedings of the constructionism 2012 conference – Theory, practice and impact* (pp. 490–499). Athens: National and Kapodistrian University of Athens.
28. The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5–8.
29. Vergnaud, G. (2008). Réponses de Gérard Vergnaud. In M. Merri (coord.), *Activité humaine et conceptualisation- questions à Gérard Vergnaud* (pp. 341–357). Toulouse: PUM.

Chapter 9
Scaffolding for Inquiry Learning in Computer-Based Learning Environments

Emily B. Moore, Mario Mäeots, and Zacharoula Smyrnaiou

9.1 Introduction

Inquiry-based science learning (IBSL) is an innovative approach to science education that situates learning in problem-solving activities or investigations of phenomena grounded in authentic science practices. Involving students in real science, technology, engineering, and mathematics (STEM) practices entails engagement in complex situations that necessitate expert scaffolding and epistemological guidance to facilitate student learning. To address this challenge, computer-based learning environments have been developed and assessed on the quality of support they provide and their consequent efficacy (e.g., [1, 2, 3]). The virtual scaffolding designed into the learning environments is a major source of this necessary support, as scaffolding can determine the structure of the learning task, guide learners through key components of the learning environment and conceptual development, and shape their performance and understanding of the task.

With such a strong role in influencing student outcomes, we believe that scaffolding is an integral and essential component of effective computer-based learning

E.B. Moore (✉)
Department of Physics, University of Colorado Boulder, Boulder, CO, USA
e-mail: emily.moore@colorado.edu

M. Mäeots
Faculty of Social Sciences and Education, Institute of Education, University of Tartu, Tartu, Estonia
e-mail: mario.maeots@ut.ee

Z. Smyrnaiou
University of Athens, National and Kapodistrian, Zografou, Greece
e-mail: zsmyrnaiou@ppp.uoa.gr

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_9

environments. Unfortunately, there lacks consensus on the types of scaffolding available to designers of computer-based learning environments, the role of scaffolding types, and to some extent, the definition of what should be considered as scaffolding [4]. In this work, we seek to establish a common framework of scaffolding types and their outcomes as a grounded reference for researchers and designers of educational environments.

To move towards this goal, we start by focusing on the following two research questions:

1. What types of scaffolding are designed into and emerge from different computer-based learning environments?
2. How does scaffolding designed and integrated into different computer-based learning environments support inquiry learning?

For this purpose, we utilized a broad definition of scaffolding, allowing for the possibility of new scaffolding types to emerge from analysis. We consider scaffolding to be *any* designed-in element of the learning environment that serves as support to enable the student user to successfully interact with, progress through, and learn with the environment. During design, decisions must be made to address often previously unforeseen constraints and limitations, resulting in design elements serving unintended purposes. Thus, we do not consider solely the intent of design elements – we also consider their possibly unintended outcomes. As a note, we do not consider teacher or peer support within this work, though we fully acknowledge the considerable role external supports can play in student learning.

9.2 Methods

To address our research questions, in-depth knowledge of the design of learning environments is required. From the design and research expertise of each author, we selected three learning environments for discussion and comparison, including: PhET Interactive Simulations [5], ETL E-slate Microworld [6], and Young Researcher [7]. From these comparisons, we compiled a list of the many design features that serve to support students' interactions with, progression through, and learning from, the environments. We found some features were common to all the environments, while others were individual to each. We then collaboratively sorted this list into scaffolding categories, resulting in the five general scaffolding types presented below.

9.3 Computer-Based Learning Environments

Each of the three learning environments analysed are unique. Here we briefly describe each learning environment and introduce the philosophy underpinning their design.

9.3.1 PhET Interactive Simulations

The PhET Interactive Simulations project at the University of Colorado Boulder develops interactive computer simulations (sims) for teaching and learning science [8]. The goals of the PhET project are to create effective research-based sims for science learning that engage students in authentic inquiry while supporting student ownership in the learning process and make PhET sims accessible and flexible for teachers and students in diverse learning environments around the world. The PhET project has developed over 130 sims on science and mathematics topics, available at http://phet.colorado.edu. PhET's design principles [9, 10] include – emphasizing connections between science and everyday life and making the invisible visible (atoms, electrons, field vectors, etc.), including visual models used by experts and implicitly scaffolding learning [11, 12]. The results are interactive sims that encourage learning through engaged exploration [13]. All of the sims are available for free and are translatable – with sims available in more than 70 languages. PhET sims are used by teachers all over the world with students from primary school through college in multiple modes of instruction – e.g., in-class activities, teacher-led demos, and as part of homework assignments. We utilized the *Build a Molecule* simulation for specific scaffolding examples.

9.3.2 ETL E-slate Microworlds

The Education Technology Lab (ETL) E-slate Microworlds project at the National and Kapodistrian University of Athens develops microworlds [14] for teaching and learning a variety of topics, including science, mathematics, and history. Many of the microworlds are available for free at http://etl.ppp.uoa.gr/index.htm. The goal of the ETL E-slate microworlds project is to create half-baked microworlds, specifically designed to challenge students to make sense of how the microworld works through changing it as they explore their own ideas [14].

Scientific microworlds engage students in constructionist game modeling activities, considered part of the inquiry learning process [6]. Working in groups with constructionist game microworlds that invite students to explore the fallible model underpinning the game, and change it so as to create a new game, provides students opportunities to bring into the foreground their conceptual understandings related to scientific phenomenon. E-slate microworlds utilize implicit scaffolding – rather than explicit scaffolding – in their design. Pedagogically and scientifically appropriate models are carefully designed in terms of objects, properties, key concepts, and relationships between concepts and representations. Each microworld is "open" and permits the creation of more models. The microworld *3D Juggler* was utilized for specific scaffolding examples.

9.3.3 Young Researcher

The computer-based learning environment Young Researcher (http://bio.edu.ee/teadlane) is designed for students to learn biology topics through inquiry. The learning environment is designed so that students feel that they are "inside the inquiry process". The learning environment is a virtual classroom with a virtual teacher and students. The tasks are structured so that it looks like a real lesson, where the teacher initiates inquiry by presenting a problem that needs to be solved (e.g., *Why does our pulse and breathing rate change?* and *Why do organisms need water?*) and then guides students through the inquiry process. Each tasks follows a pre-defined sequence of inquiry. First, students identify the problem, then students formulate a research question and a hypothesis, plan an experiment, carry out an experiment (real or virtual), analyze their results, and draw conclusions [7]. The learning environment is complete with a variety of features to support the inquiry process.

9.4 Scaffolding Types

From our findings, computer-based learning environments can include five general types of scaffolding. For each scaffolding type, we provide a description, examples from the computer-based learning environments, and suggestions of how this type of scaffolding supports student learning – based on our observations of student use.

9.4.1 Scope of Domain Knowledge

A foundational way in which designers scaffold student learning is through selecting the domain knowledge goals to be targeted by the learning environment. Domain knowledge goals can be chosen based on students' age and grade level, location within a particular curriculum and the learning environment's intended use (for example, single day or multi-day unit). By selecting domain knowledge goals, designers are narrowing the scope of the learning environment from a general topic (e.g., science, chemistry, or molecules) to specific learning goals (e.g., using chemical formulas to represent simple molecules), and consequently adapting the learning environment to meet the students' learning needs.

Individual learning environments can address a broader or narrower set of goals – but any one learning environment cannot address *all* goals. For example, in the PhET simulation *Build a Molecule*, the domain knowledge targeted includes chemical formulas and coordinating multiple representations of molecules. In the E-Slate microworld, *3D Juggler*, the domain knowledge targeted is broader, including motion and collisions. With the broadest goals of the three learning environments, Young Researcher units address the inquiry cycle in general, along with more specific domain knowledge goals. Each learning environment could have had more or less domain knowledge goals, but instead chose specific learning goals at the intersection of their design philosophies and their targeted student population.

Specifying the domain knowledge goals begins the tailoring of the learning environment to the students' range of competence. This can result in learning environments that contain achievable goals for students, avoids oversimplifications that lack authentic inquiry, and provides direction for further scaffolding.

9.4.2 Inquiry Pathway

The ways in which designers envision (and ultimately, support) students to engage with the content determines the inquiry pathway – the student's process through which the content is addressed. All support provided to students (e.g., teacher facilitation, textbooks, learning environments) is based on the underlying beliefs about teaching and learning from the source of support. The structure of each computer-based learning environment depends on what its designers, and implementers, believe are effective ways for students to be engaging with content. The envisioned inquiry pathway shapes the design of computer-based learning environments, which in turn determines the ways in which students engage with, and learn from, any learning environment.

PhET simulations emphasize learning through engaged exploration of the learning environment. Through the implicit scaffolding designed into the PhET simulations, students are supported to explore, ask their own questions, form hypotheses, and collect information to answer their questions. Students can explore without explicit guidance, completing self-motivated "micro inquiry cycles," or students can be guided through a more explicit inquiry process with the facilitation of a teacher or written activity. E-slate microworlds emphasize scientific modeling practices, presenting "half-baked" models for students to experiment with according to their own ideas. Young Researcher encourages a more explicit engagement in the inquiry process. Students are prompted and supported throughout the inquiry process, from initial identification of a problem to the final drawing of conclusions.

Throughout discussions of the three learning environments, we found these early decisions regarding domain knowledge goals and inquiry pathway influence much of the choice and design of later scaffolds. These choices determine the specific scaffolds that complement the specific domain knowledge addressed, and often narrow the range of scaffolds available for implementation within the learning tool. For example, the emphasis on inquiry through engaged exploration led to the choice to not include explicit text prompts or questions within PhET simulations, while the goal of making the inquiry process explicit resulted in a more structured inquiry pathway in Young Researcher.

9.4.3 Sequencing

Sequencing scaffolds within learning tools include all the ways students are supported to advance (or not) through the environment. We found two dimensions along which sequencing can occur: across the learning tool as a whole (across all of the knowledge domain goals) and across subtopics.

Within sequencing across domain knowledge goals lies a spectrum of designed-in structure. At one end of the spectrum lies heavily structured learning tools, where the design of the tool results in students following a single, pre-determined sequence – students must complete tasks in a specific order. At the other end of the spectrum lies environments designed with little or no constraints regarding sequence – students can choose to utilize any components of the environment at any time. Between the ends of the spectrum lies a range of options, where students can explore some portions of the tool as they choose while other portions require specific ordering (as in Young Researcher), or exploration is allowed across the tool with sequencing supported through implicit scaffolds (as in PhET simulations) or teacher facilitation (as in E-slate microworlds).

How a learning environment is sequenced helps to define the learning task for students. For example, in Young Researcher, students navigate a particular module through pre-defined inquiry steps, supported by a virtual professor. These inquiry steps are shown to students in sequence, indicating that the task is to 'complete the inquiry sequence'. Most PhET simulations consist of two to four screens. As students engage with PhET simulations, the task becomes 'explore each screen'. E-slate microworlds typically contain a single screen, indicating the task is 'explore this screen'.

The sequencing of the learning environment indicates to students how to navigate the environment, and where conceptually they should be focusing their attention. Commonly, the less structure built into a learning tool, the more external support is expected during implementation, either through direct facilitation, guiding handouts, or both in combination.

In contrast to sequencing across domain knowledge concepts, there is also sequencing within concepts. This includes scaffolds to support understanding of individual concepts – what resources are made available (e.g., representations to interact with; models to explore; text, video or audio supports) and how students are to access, interacts with, and engage with the resources.

Sequencing within domain knowledge goals breaks down larger ideas into a series of increasingly complex ideas, supporting students in progressing through more sophisticated understanding of the content. Within PhET simulations, each screen addresses sub-topics, building to engagement with all of the environment's learning goals. The *Build a Molecule* simulation is sequenced through the use of three screens, the Build Molecules, Make Multiple, and Larger Molecules screens. Each screen focuses student interaction on a specific component of chemical formulas – by first building a single molecule and connecting their molecule with its chemical formula, then building multiple molecules and recognizing how chemical formulas can indicate multiple, and then building more complex molecules with chemical formulas containing many elements.

While this work does not focus on external scaffolds, there appears to be interplay between the amount of structure built into a learning tool and the amount of external facilitation expected for effective implementation.

9.4.4 Feedback

Feedback scaffolds are often the primary scaffolding type considered in the literature and by educational designers [15]. Feedback scaffolds include the ways in which a learning environment responds to the students' actions or choices. These scaffolds can be designed in many ways to support different outcomes – feedback can be designed to allow the student to know they have successfully interacted with an object, to make a connection between two representations, to provide confirmation on whether or not a choice was correct, and to indicate what students should do next. Feedback can support one or many of these outcomes simultaneously.

Feedback scaffolds can be implicit or explicit and can be considered as affordances or as productive constraints. In the *Build a Molecule* simulation, students receive feedback that they have successfully built a molecule when the name of that molecule appears above it. To indicate that putting together a particular set of atoms does not result in a molecule, the atoms do not "stick" together. Within 3D Juggler, students have available a set of sliders (the sphere mass and size, the shot azimuth and altitude) which control several parameters that affect the observed motion. Young Researcher provides feedback through responses to multiple-choice questions.

Feedback is a primary benefit to computer-based learning environments, capable of providing the student with a customized experience based on their individual inquiry pathway. By providing students with specific feedback, computer-based learning environments can mediate student learning in a 'just-in-time' fashion, without drawing the student out of their engagement and inquiry with the tool.

In fact, modifying investigations based on the new information provided by the feedback can become an integral part of inquiry, supporting students in the practice of adapting approaches and investigations as their thinking about a topic evolves. Feedback scaffolds also provide the opportunity for the learning environment to help students to find productive inquiry pathways and to steer students away from unproductive investigations.

9.4.5 Cueing

Cueing scaffolds provide students with subtle guidance to orient students to their task within the learning environment, and in understanding how to use the learning environment. In the *Build a Molecule* simulation, atoms to be used for building molecules are found in buckets. The buckets provide a cue to students that their contents can be added and removed. The sim also contains collection boxes, which start out empty; as students build molecules, the collection boxes with the corresponding molecular formula change colors to cue students to collect their molecules. Within *3D Juggler*, sliders not only allow students to change the microworld's underlying model but also provide a strong cue to students that changing the model is a goal for them. With *Young Researcher's* emphasis on investigations using the inquiry cycle, students are cued to progress through each part of the inquiry cycle in a specific order through its representation of the inquiry cycle for navigation.

Each of these cues serves to support students in successfully engaging with the learning environment. Effective design of cues can minimize the need for external, or more explicit, forms of guidance – increasing the students' independence during the learning process and simplifying classroom implementation.

9.5 Discussion

Our goal in presenting these five types of scaffolding for inquiry is to contribute to a growing body of literature attempting to develop consensus on scaffolding frameworks for computer-based learning environments. Our findings are unique in that they are the result of analyzing for emergent scaffolding themes through comparison and discussion of three distinct learning environments. This style of analysis provides an opportunity to not only inform our understanding of educational design but also strengthen community connections.

Extensions to this work could involve the inclusion of more learning environments and their designers. Future research studies could include qualitative analysis of student interactions with the learning environments, providing further insight into our interpretations of the ways the scaffolding types support student learning. Also, comparisons of different versions of each learning environment with more or less scaffolding, or different combinations of scaffolds could be conducted, to learn more about the relationships between features and student engagement and learning.

Through the comparisons carried out in this work, we were able to find interesting contrasts in design choices and locate their source within the design process. For example, by noticing that some of the learning environments make heavy use of implicit scaffolding, while others chose more explicit scaffolds led to discussions of underlying philosophies of effective inquiry pathways. Through discussions of how students were to understand how to navigate the environment, we found that all the simulations utilized cueing in a variety of ways. With a better understanding of the similarities and differences across designs and a shared terminology, we will be better prepared for collaborative and generalizable research on student learning with computer-based learning environments.

Acknowledgements This work is a result of the "Scaffolding Inquiry-Based Science Learning (IBSL) with computer environments" workshop at the 2013 STELLAR Alpine Rendez-Vous held in Villard-de-Lans, France. We would like to thank the coordinators and attendees of this workshop for their encouragement and constructive feedback.

References

1. Plass, J. L., Milne, C., Homer, B. D., Schwartz, R. N., Hayward, E. O., Jordan, T., Verkuilen, J., Ng, F., Wang, Y., & Barrientos, J. (2012). Investigating the effectiveness of computer simulations for chemistry learning. *Journal of Research in Science Teaching, 49*(3), 394–419.
2. Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58*(1), 136–153.
3. Smetana, L. K., & Bell, R. L. (2011). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education, 34*(9), 1337–1370.
4. Lajoie, S. P. (2005). Extending the scaffolding metaphor. *Instructional Science, 33*(5–6), 541–557.
5. Lancaster, K., Moore, E. B., Parson, R., & Perkins, K. K. (2013). Insights from using PhET's design principles for interactive chemistry simulations. In J. P. Suits & M. J. Sanger (Eds.), *Pedagogic roles of animations and simulations in chemistry courses* (pp. 97–126). Washington, DC: ACS Symposium Series.
6. Smyrnaiou, Z., Foteini, M., & Kynigos, C. (2012). Students' constructionist game modelling activities as part of inquiry learning processes. *Electronic Journal of e-Learning, 10*(2), 235–248.
7. Mäeots, M., Pedaste, M., & Sarapuu, T. (2009). Developing students' transformative and regulative inquiry skills in a computer-based simulation. In *Proceedings of the eighth IASTED international conference: Web-based education*. Calgary: ACTA Press.
8. Wieman, C., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. *Science, 322*, 682–683.
9. Adams, W. K., Reid, S., LeMaster, R., McKagan, S. B., Perkins, K. K., Dubson, M., & Wieman, C. E. (2008). A study of educational simulations part I-engagement and learning. *Journal of Interactive Learning Research, 19*(3), 397–419.
10. Adams, W. K., Reid, S., LeMaster, R., McKagan, S., Perkins, K., Dubson, M., & Wieman, C. (2008). A study of educational simulations part II: Interface design. *Journal of Interactive Learning Research, 19*(4), 551–577.
11. Paul, A., Podolefsky, N., & Perkins, K. (2012). Guiding without feeling guided: Implicit scaffolding through interactive simulation design. In *Proceedings of the 2012 physics education research conference*, 1513 (pp. 302–305). AIP Press.
12. Podolefsky, N. S., Moore, E. B., Perkins, K. K. (2013). *Implicit scaffolding in interactive simulations: Design strategies to support multiple educational goals*. http://arxiv.org/abs/1306.6544. Visited 03 March 2013.
13. Podolefsky, N. S., Perkins, K. K., & Adams, W. K. (2010). Factors promoting engaged exploration with computer simulations. *Physical Review Special Topics – Physics Education Research, 6*, 020117.
14. Kynigos, C. (2007). Half-baked logo microworlds as boundary objects in integrated design. *Informatics in Education – An International Journal, 6*(2), 335–359.
15. Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153–189.

Chapter 10
Multimedia Applications by Using Video-Recorded Experiments for Teaching Biology in Secondary Education

Maria Dokopoulou, Evangelos Bozas, and Evangelia A. Pavlatou

10.1 Introduction

Information and Communication Technologies (ICTs) are defined as "a diverse set of technological tools and resources used to communicate, and to create, disseminate, store, and manage information" [1]. These technologies include computers, the internet, broadcasting technologies and telephony and enable tools for educational change. ICTs can enhance the quality of education by increasing learner motivation and engagement, facilitating students' interest and active participation. Particularly, in school science activities ICTs offer a range of different tools, including multimedia software and simulation of processes, information systems, publishing and presentation tools, digital recording equipment and computer projection technology [7].

M. Dokopoulou (✉)
National Technical University of Athens, School of Chemical Engineering,
Sector of Chemical Sciences, 9, Heroon Polytechniou Str., Zografos Campus,
Athens GR-15780, Greece

The Institute of Educational Policy, 36, An Tsoha Str., Athens GR-11521, Greece
e-mail: mdokopoulou@iep.edu.gr

E. Bozas
Pediatric Research Laboratory, Faculty of Nursing, University of Athens,
123, Papadiamantopoulou Str., Athens GR-11527, Greece
e-mail: ebozas@nurs.uoa.gr

E.A. Pavlatou
National Technical University of Athens, School of Chemical Engineering,
Sector of Chemical Sciences, 9, Heroon Polytechniou Str., Zografos Campus,
Athens GR-15780, Greece
e-mail: pavlatou@chemeng.ntua.gr

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_10

However, many science teachers report that the officially approved software they intended to use was either unavailable or more difficult to use than they expected. They also express the need for equality in accessing hardware and software for all students, both in class as well as outside the classroom environment [2]. In the field of biology, many studies [8] reveal a strong correlation between the use of ICT tools and the positive attitudes towards biology or the effectiveness of teaching by increasing knowledge and academic achievements [10].

Biology teaching takes place in one or more of three different kinds of environments: the classroom, the laboratory and the fields. Multimedia technologies translate features of each of these three learning environments to the biology student's desktop. Biology teachers use external representations taken from textual and pictorial descriptions of biological phenomena to symbolic and graphical representations of biology concepts and principles. ICTs offer teachers the opportunity to take advantage of these representations in order to present biological phenomena as well as biology concepts that change in time and space [4]. In this framework, biology teachers tend to adapt ICT into their teaching routine not only in the classroom but in the laboratory as well.

Video technology is one of the technologies of information and communication that has found an important niche in the teaching environment due to the potentiality to provide audio-visual stimulation. There are two areas of benefit that video provide in teaching environment. One of these is related to the way in which video stimulates concentration and motivation of students throughout the teaching process. The second area of benefit deals with the power of video in helping students conceptualize and internalize difficult and abstract topics [9].

School biology experiments are often difficult to carry out due to the lack of highly cost equipment and the limited school time. The increasing number of students in the class makes it even more difficult for the teacher to fulfill his/her learning objectives. In this paper, multimedia applications are presented including video-recorded experiments that could be implemented in teaching biology in secondary education. These digital learning objects are introduced in the "enriched" e-biology textbook and are uploaded on the "Digital School-Digital educational material" platform on the "Interactive school e-books" sub-platform as well as separate digital objects on the "Photodentro" sub-platform.

10.1.1 Digital School Platform

The platform "Digital School-Digital educational material" includes the official digital teaching material of the Greek Ministry of Education [11]. It is a component of the "New School", where the use of ICTs tools has a basic role in recent Greek educational reforming regarding: (a) the content of the curriculum and school knowledge, (b) teaching and learning, (c) the relationship of teachers and students and (d) the relationship of parents and school. One of the actions of "Digital School-*Digital* educational material" is the production of interactive digital material consisted with the curricula for all classes and subjects. This platform was designed in such a way to enable students having easy access even from home so as they can consolidate the material and practice with their own particular pace. It also provides a powerful tool to the teachers with that could be profitable in the design of effective science teaching in the classroom.

The official website (www.dschool.edu.gr) has been upgraded recently (September 2013) and contains interactive e-textbooks (http://ebooks.edu.gr) and the National Learning Object Repository (LOR) – "Photodentro". LOR is an online digital library of searchable learning objects that have been catalogued for educational purposes, along with a set of management, search and access mechanisms. It stores learning objects and their metadata. Metadata allow the object to be indexed, making retrieval and reusing of learning material technologically easier.

Learning objects can be ascribed as any digital resource that has a clear educational purpose, is reusable and is functionally self-contained. Furthermore, these objects need to serve goals of the national curricula, to be available on line and to be provided under a cost-free license for educational purposes [5].

In conclusion, "Digital School-Digital educational material" platform offers free access to students, teachers and parents. It includes several simple applications, such as adding links to official organizations websites (e.g. WHO) and electronic encyclopedias (e.g. Wikipedia) and complex applications as presentations, educational games and video-recorded experiments.

10.2 Video-Recorded Experiments in Biology

For the majority of researchers, laboratory work is considered to be of great importance in science education and some support that it is the defining characteristic of this component of the school curriculum. However, research on aspects of laboratory work and its consequences does not provide strong support for this view. Students don't point to much mental engagement during laboratory work as this work often cognitively overloads students with too many things to recall [3]. Several studies examine the role of video-recorded experiments showing inquiry-based teaching with video presentations ensure learning permanency and improvement of mental process skills [9].

In this paper, five video-recorded experiments are presented that will be utilised in order to enrich the biology e-textbook used in the second grade of the upper secondary Greek education system – Lyceum. The topics are according to the student's book and suggest the study of Molecular and Cell Biology according to the national curriculum guidelines. They are simple experiments realised in Pediatric Research Laboratory of National and Kapodistrian University of Athens that aim to provide students with the basic information of how to use a microscope, to observe nucleus from plant cells, to isolate nucleic acids from human cells and to study mitosis and protein denaturation. Each one of them is part of an interactive application comprised by texts, images and tests.

10.2.1 Further Use of the Applications in the Learning Environment

These learning objects can be used in the classroom, in the school laboratory or at students' home as free access to the data of the applications is provided. One of the ways to introduce a student to an experiment is to demonstrate it first. A recorded video is easier to use as a demonstration. Given that editing different video clips in a suitable format and adding multimedia tools (e.g. sound etc.) needs a lot of work biology teachers could use them instead of conducting the relevant experiments in the school lab, elaborating time for class preparation or in-class discussion.

Teachers are able to download either the full application or the embodied videos separately and use them as a part of a lesson plan giving them the opportunity to create their own activities to serve special teaching goals. As these digital video clips are easily controllable, teachers can demonstrate fine details through the use of slow motion, therefore having the flexibility to demonstrate scientific concepts that would otherwise be difficult to do so.

Students, on the other hand, could use them in many phases of the learning procedure, e.g. before conducting a laboratory experiment or for preparing the next lesson. Consequently, these videos could be used in a flipped-classroom project where students study the experiment at home and discuss it in the classroom having more time for hands-on activities in the school. Students also have the chance to use these videos as a part of their laboratory report. Therefore, they need to decide which part of the video they ought to choose in order to emphasize the appropriate content. The use of a video in a student's presentation opens up opportunities for improvement of communication skills and discussion amongst students and teacher that do not exist in a paper laboratory report [6].

Finally students may use these applications while working at a school project or revising the relevant subject. They can review the same experiment as many times as they want and spend more time observing the phenomenon which leads to scientific discovery and understanding.

10.2.2 Description and Use of a Microscope

The microscope is one of the most useful instruments in a biology laboratory. This application includes two streaming videos (Fig. 10.1). The first one describes the parts of an optical microscope and the second gives the necessary directions for its use.

Watching the video students could learn more about the history of microscopes, the parts by which a microscope is constructed and how to calculate the final magnification of the objects. An interactive test is used for the final evaluation of the subject. This application is very useful for students' preparation before their first experience with a microscope. In cases of non-equipped schools with microscopes, this application is invaluable in familiarizing students with a microscope and its function.

Fig. 10.1 Description and use of an optical microscope

10.2.3 Observation of Nucleus from Plant Cells

This application consists of a video describing the preparation of a plant tissue from an onion peel before observing it through the use of microscope (Fig. 10.2). The cell of an onion peel consists of a cell wall, cell membrane, cytoplasm, nucleus and a large vacuole. The nucleus is present at the periphery of the cytoplasm. The vacuole is prominent and present at the centre of the cell. It is surrounded by cytoplasm. The presence of a cell wall and large vacuole are indicators that help identify plant cells, such as seen in the onion peel.

This application offers students the chance to observe all the parts of a plant cell and especially nucleus. It could be used not only for students' preparation before their practice but as a demonstration in case there is limited school time or lack of microscopes in the school laboratory. Students in the school lab can repeat the same experiment using different types of plant or animal cells and compare their pictures with those included in the above application. Discussing the preparation of the different tissues or the problems that had to be solved using microscope equipment, students are prompt to develop several learning skills.

Fig. 10.2 Observation of nucleus in plan

10.2.4 Isolation of Nucleic Acids from Human Cells

The video that is embedded in this digital application shows a rather simple way to isolate nucleic acids from mouth cells (Fig. 10.3). It could incite the interest of the students as it gives them the chance to visualise nucleic acids. This application can be used as an introduction to the study of DNA and RNA. Students often believe that they are going to see the double helix of DNA and are surprised by the final structure of the white strands that indicates nucleic acids. Biology teachers can use this application in order to minimize misconceptions regarding DNA structure and describe the difficulties in the discovery of the molecular structure of DNA.

Given that the video-recorded experiment is conducted using simple materials of everyday life like soap, salt and alcohol students may repeat it even at home using different type of samples like plant cells from fruits. Comparing their final products with those presented in the video they could make suggestions about the different amount of nucleic acids in different type of organisms or the difficulties they faced up during the extraction of these substances.

Fig. 10.3 Isolation of nucleic acids

10.2.5 Mitosis

This multimedia application includes a recorded video of an experiment for the observation of mitotic division in the cells of an onion root tip. Although it is considered a rather simple experiment teachers find it difficult to handle all the necessary equipment and they also feel insecure about the final results. Furthermore, more than 3 days are needed for the preparation of the root samples which must be gathered very early in the morning when it is still dark (Fig. 10.4) All these issues elaborate many difficulties in time management of lab planning and realisation in school lab.

The application offers solutions to all these problems as it contains images of all the stages of mitosis and experimental procedure giving teachers the necessary material they need in order to achieve the most of their goals arousing students' interest and cultivating critical thought (Fig. 10.5). Students could also use the embodied video separately in a lab presentation or a school project comparing it with relevant videos or pictures from the same experimental procedure in human cells. They could focus on the different images of mitotic stages and make suggestions about the number and the structure of chromosomes.

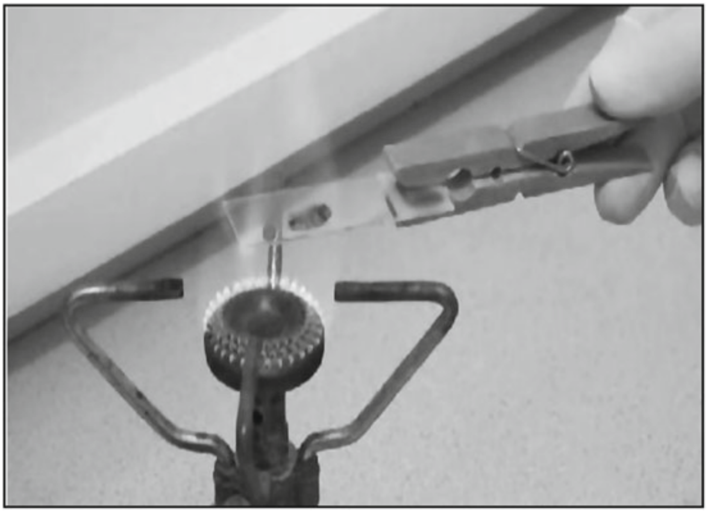


Fig. 10.4 Preparation of the root tips

Fig. 10.5 Metaphase in plant cells

10.2.6 Protein Denaturation

The video-recorded experiment of the application demonstrates the denaturation of proteins structure due to heat and the influence of several chemical substances (Fig. 10.6). The application contains everyday life examples showing how proteins denaturation affects our health or food consumption. Given that this experiment is time consuming, the application allows teachers to overcome school time restrictions and focus on discussion with students regarding the changes in the protein molecule and how these changes influence proteins' function.

Since denaturation is a process that concerns issues from chemistry and biology science, this application as well as the videos included therein could be very useful to science teachers. Effective teaching this specific thematic unit is expected to help students to build a positive attitude towards sciences and technology since they are strongly connected with their environment.

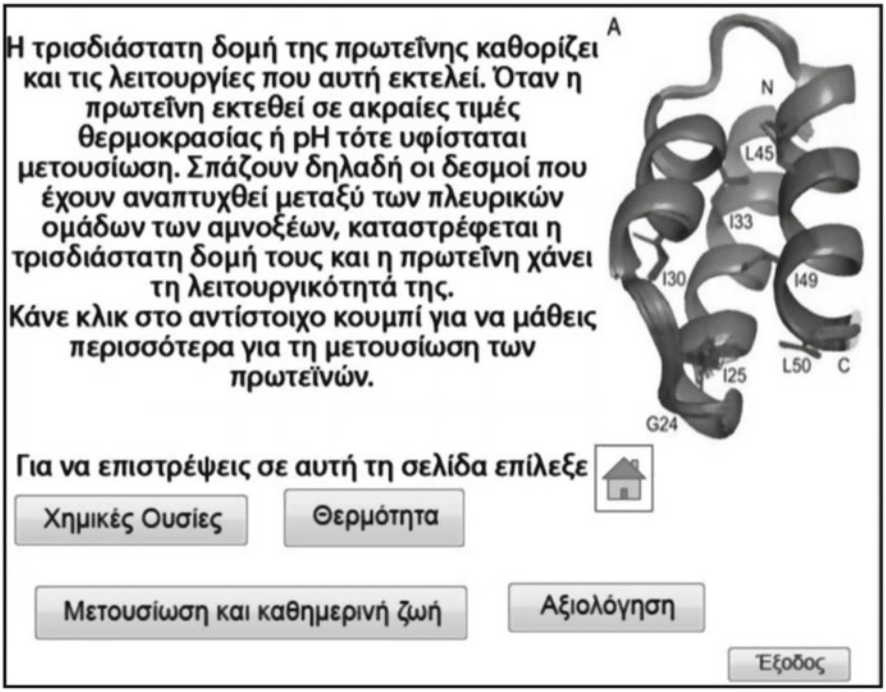


Fig. 10.6 Protein denaturation

10.3 Specification

All the above applications contain at least one video-recorded experiment. Video capturing and editing software were used for the production of these videos. These videos were embedded in the Adobe Captivate software in order to create the final application.

10.4 Conclusion

This paper presents some of the digital learning objects that are designed to be used as a supplementary digital material in biology teaching in Secondary Education in Greece. Although biology experiments for Secondary School are quite simple, special equipment (e.g. microscope) and plenty of school time for preparation is needed. This explains why many teachers avoid conducting them.

These multimedia applications enable the teacher to use easily ICT tools either in the classroom or in the laboratory. Teachers could replace laboratory experiments by the recorded video-experiments in order to overcome possible practical difficulties such as a crowded classroom or facing the lack of equipment. Also, these videos can be used by teachers for preparing their students for the experiments conduction. Furthermore, teachers can watch the videos beforehand in order to decide how to incorporate them in their lesson plan, taking into consideration the particular needs of their students. Finally, these videos could be served as visual material that provides opportunities for teacher-student interaction, reflection and further discussion.

In particular, these videos allow students to make an immediate observation in case the experiments conducted by them have not produced the theoretically expected result. They also give students the opportunity to study the experimental procedure before its practical application. Thus, students have time to think, discuss and reflect through the immediate visual feedback without spending teaching time on dealing with apparatus, instructions and recipes. Alternatively, they can construct their new knowledge by comparing the video recorded experiment with the experiment that is demonstrated by the teacher or executing the experiments by themselves in order to build the new concept.

Also, even if we had the required equipment and time, these step-to-step videos are still useful because they provide students the chance to execute the experiment as many times as they need in order to study and understand it. It is important to keep in mind that today students belong to the ICT generation and we need to motivate them with key factors that trigger their interest. If motivation is not our top priority, no matter how well a lesson plan is developed, students will simply drift away.

However, it is necessary to set these applications in a real environment classroom in order to evaluate their use and establishing the necessary changes for their improvement.

Changes in the learning environment and traditional teaching techniques are necessary in order to create a new stepping stone relationship between the student and the computer. These learning objects can lead to the change of the traditional school that gradually moves towards the "new school" in which courses are designed in such a way to ameliorate the learning process in all subjects such as biology.

References

1. Blurton, C. (1999). *New directions of ICT-use in education*. Available on line http://www.unesco.org/education/educprog/lwf/dl/edict.pdf
2. Gundy, M., & Berger, M. J. (2013). Integration of laptop computers in High School Biology: Teacher perceptions. *Journal of Information Technology and Application in Education (JITAE), 2*(1), 33–46.
3. Hart, C., Mulhall, P., Berry, A., Loughram, S., & Gunstone, R. (2000). What is the purpose of this experiment? Or can students learn something from doing experiments? *Journal of Research in Science Teaching, 37*(7), 655–675.
4. Kubiatko, M., Yilmaz, H., & Haláková, Z. (2012). The attitudes of Slovakian and Turkish high school students to the ICT used in biology according to gender and age differences. *Energy Education and Technology Part B: Social and Educational Studies, 4*(1), 433–446.
5. Megalou, E., & Kaklamanis, C. (2014). Photodentro LOR. The Greek National Learning Object Repository. In *INTED2014 Proceedings, 8th international technology, education and development conference* (pp. 309–319). Valencia, Spain, 10–12 March.
6. Michel, R. G., Cavallari, J. M., Znamenskaia, E., Yang, K. X., Sun, T., & Bent, G. (1999). Digital video clips for improved pedagogy and illustration of scientific research—With illustrative video clips on atomic spectrometry. *Spectrochimica Acta Part B: Atomic Spectroscopy, 54*(13), 1903–1918.
7. Osborne, J., & Hennessy, S. (2003). *Literature review in science education and the role of ICT: Promise, problems and future directions*. Bristol: Nesta FutureLab. http://www.nestafuturelab.org/research/reviews/se01.htm
8. Romi, S., Hansenson, G., Hansenson, A., & Gan, R. (2002). E-learning: A comparison between expected and observed attitudes of normative and dropout adolescents. *Education Media International, 39*(1), 47–54.
9. Sever, S., Oguz-Unver, A., & Yurumezoglu, K. (2013). The effective presentation of inquiry-based classroom experiments using teaching strategies that employ video and demonstration methods. *Australasian Journal of Educational Technology, 29*(3), 450–463.
10. Sorgo, A., Hajdinjak, Z., & Briski, D. (2008). The journey of a sandwich: Computer based laboratory experiments about the human digestive system in high school biology teaching. *Advances in Physiology Education, 32*(1), 92–99.
11. www.digitalschool.minedu.gov.gr

Chapter 11
Inquiry and Meaning Generation in Science While Learning to Learn Together: How Can Digital Media Provide Support?

Zacharoula Smyrnaiou, Foteini Moustaki, and Chronis Kynigos

11.1 Introduction

Science education has, in recent years, been the forum for new pedagogic approaches and visions where the main focus is on the activation and enhancement of students' engagement and meaning generation in ways that differentiate by far from past practices [10, 12]. These approaches aim to help students acquire experiences around scientific concepts which have been shown to be difficult for them to grasp. Adopting constructivist/constructionist teaching and learning models inevitably leads to the application of a pedagogy promoting activity which is: Hands-On – by enabling parallel science performance and experimentation with meaning generation, acquisition of understanding and construction of knowledge [5, 11]; Minds-On – by challenging and meaningfully engaging students in high-order mental processes through a continuous and constant exchange of questioning and proof seeking in a framed context of focused scientific activities that address the pursue of handling the physical laws that surround the universe [4]; Authentic – by posing students real-life questions in a format of problem-solving activities that require consideration of their personal experiences and evaluation of informed expert sources; dealt through collaborative negotiation and in a multi-level perspective in order to result in documented applications and logical generalizations to broader ideas [8, 13]. On the other hand, there are a few researches that have focused on the L2L2 process.

Z. Smyrnaiou (✉)
University of Athens, National and Kapodistrian, Zografou, Greece
e-mail: zsmyrnaiou@ppp.uoa.gr

F. Moustaki • C. Kynigos
Educational Technology Lab, School of Philosophy, Faculty of Philosophy, Pedagogy and Psychology, Department of Pedagogy, National and Kapodistrian University of Athens, Athens, Greece
e-mail: fotmous@ppp.uoa.gr; kynigos@ppp.uoa.gr

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_11

Wegerif et al. [16] support that L2L2 is not a simple process, but instead it requires a complex competence which is independent of the domain knowledge. But it is through this complex competence that students are triggered to get involved in higher order mental processes that require critical and analytical thinking as well as metacognitive awareness, turning the learning procedure into a deep access process into the cognitive issues under negotiation.

11.2 Background and Theoretical Frame

Several experiments have been conducted on the crucial aspects of L2L2. These experiments have shown that the collective learning process has the potential to proceed and evolve in parallel with the shared mental models of group members (taskwork mental models and teamwork mental models) within an open-ended challenge [2]. Other attempts have concluded that socio-metacognition (peer assessment) extends knowledge for group members and managing group learning requires knowledge of the learning styles and strategies of other members of the group. Distributed leadership is considered as an important aspect of L2L2, and Gressick and Derry [7] argue that the specialization of individuals in specific leadership roles within groups as well as the different forms of participation can be sources of distribution of leadership in online groups. Recent studies have referred to the mutual engagement of group learners that can be achieved through critical discussions, creative design and manipulation [14, 15] since it is through this mutual contribution that alternative perspectives open up and activate students' multi-faceted level of stream of thought.

L2L2 is an important aspect of collaboration as it refers not only to what the students learn, but to how they learn to collaborate and communicate with others inside a group and jointly reflect on their work and their functioning as a team. We perceived distributed leadership, mutual engagement, peer assessment and group reflection [16] as the four key concepts for L2L2 and we sought for ways that these key concepts facilitated or enhanced the meaning generation process.

In this article, we are interested in collaborative meaning generation in Newtonian Physics through the Metafora web Platform. We asked students to create a model within 3d Juggler that would make one of the Juggler's balls hit a specific racket (and other scientific problems). As they addressed these "challenges", we focused on the strategies they devised – using Metafora Platform – for making sense of the "shot azimuth" and the "shot altitude" parameters and the effect these two parameters had on the models they were creating. Our aim was to evaluate our design choice to include in the microworld parameters that correspond to scientific conventions so that students can argue from a particular point of view and focus on an explicit end product. In addition, our analysis focused on the description of instances where the process of meaning generation (MG) triggered (or not) one of the four L2L2 elements and the description of instances where the different elements of L2L2 seem to influence and shape the process of meaning generation (MG).

11.3 The Metafora Platform

The Metafora Platform [6] is a completely web-based environment putting at students' disposal means and tools such as a set of microworlds which deal with specific mathematics and science concepts and two WYSIWIS shared activity spaces [1]: the Planning Tool and the Discussion/Argumentation Tool, which facilitate the negotiation of scientific concepts based on the use of a special visual language. The Planning Tool is a shared workspace developed to support a group of students working together in planning their activities in advance, attributing roles and assigning tasks to the members of the group as well as in reflecting on their specific planning process. LASAD is an on-line chat tool combined with a graphical argumentation environment, designed to support synchronous discussions between collaborative learners in a generic framework of structured argumentation. Students (working individually or in groups) may communicate their ideas with their peers by adding textual contributions inside a shared workspace. Through the use of such an argumentation space students are enabled to collaboratively expand and explore their dialogic space on issues concerning authentic science challenges.

In particular, the Metafora Platform hosts Juggler [9], a 3d environment for building models of 3d motions and collisions inside a Newtonian space. 3d Juggler [9] is a microworld (Fig. 11.1) within which the students may create models for simulating motions and collisions in 3d space [13]. Apart from controlling parameters like Sphere Mass, Gravity Pull and Wind Speed, the students may also give their models behaviours that are defined by the "shot azimuth" and the "shot

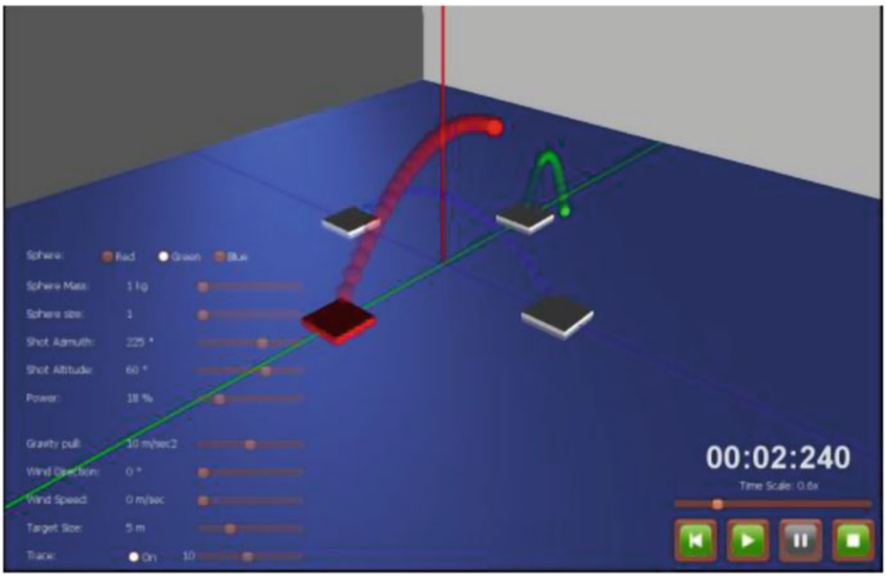


Fig. 11.1 The 3d Juggler microworld

altitude" parameters. Shot azimuth and shot altitude are conventions, as they exist only inside the microworld and just because this is a 3d microworld and motion inside it can be defined in the X, Y and Z direction.

11.4 Research Methodology

For the evaluation of the users' learning experience, we used a design-based research method [3] which entailed the 'engineering' of tools and tasks, as well as the systematic study of the forms of learning that took place within the specific context defined by the means of supporting it.

11.4.1 Context and Participants

The main study took place at the 1st Experimental High School of Athens. This is a public secondary education school, located in a central Athens area (Plaka). This school is one of the 15 Experimental High Schools that have been formally established by the Ministry of Educational Affairs to operate in Greece with the aim to promote the implementation of pedagogical innovations and facilitate pedagogical research. At the time of the research, one of the authors of this paper was the Chairman of the school's Scientific Supervisory Board.

The study started in early March 2012 and was completed in June 2012. The implementation of innovative activities in rigid educational systems such as the Greek one is bound to produce – at different levels and extent – some kind of perturbation. For this reason, the Metafora main study took place in after school hours (Saturday from 3:00 p.m. to 7:00 p.m).

We worked with a group of fourteen (14) students at the ages of 13–14 years. More specifically, six (6) second grade high school students and eight (8) third grade high school students. The students were divided in three groups of 4 or 5. The groups were divided in two subgroups of 2 or 3 students each. It is important though to mention that the students had decided on the group formation themselves. One group of 4 students volunteered to work using the English version of the Metafora Platform and to answer any questions in English (ENG group).

A team of researchers participated in data collection session, using a Research Protocol (worksheet) with the warm-up and the main challenges, a screen-capture software (HyperCam), a camera and tape-recorders. One researcher was occasionally moving the camera to all groups to capture the overall activity and other significant details as they occurred. Background data was also collected (e.g. students' worksheets and observational notes) and all audio-recordings were transcribed.

11.4.2 Activities

In the context of exploratory learning, we studied the way students got engaged to several methods and techniques in order to explore the meanings generated in Newtonian Physics and how these were mediated by the Metafora Platform (across the different tools: Planning Tool, microworld, LASAD).

During the first session, the students were given a set of photos showing people working together to achieve common goals. They were told to discuss this matter and answer a set of questions based on collaborative learning and working with others. The next part of this session concerned a game in the schoolyard. The students were told to shape either a triangle or a square and throw different balls to each other. After this activity, students started to think about the physical quantities and the link between physics and real-life instances. In the final phase, they were presented the Planning Tool. Students had to create an instance based on how Galileo worked to prove a statement. This was the first attempt that required the students to deal with an incident regarding the scientific method.

For this reason, in the second session, they used LASAD to create maps and communicate between the different groups and collaborated to create maps about Galileo's plan. The students were asked at this point to play with the 3d Juggler microworld. They were asked to manipulate the sliders in order to control the values of the parameters affecting a ball's motion in the 3d space. After feeling comfortable with the interface, they were given a series of challenges. The goal of this stage was for the students to collaborate with each other using some of the Metafora Platform tools (Planning Tool, LASAD) to discover the role of the variables of the microworld and how they affect the Newtonian Physics laws of motion.

In the session started, the students faced two major microworld challenges, which the students needed to address by collaborating as a group through LASAD and the Planning Tool. In the context of creating a model of the real world, they faced the challenge of controlling the motion of the balls in the microworld in order to enhance their insight of the "physics" behind the 3-D motion of the objects in the microworld.

During the last sessions, the students were asked to play three digital games and then answer several questions. These were in the context of the evaluation of their progress in the game, the "physics" behind these games and the changes they would make if they wanted to make the game a better experience for the users. Finally, they were asked to create a Juggling game using the story telling tool provided (Pixton) or any other similar tool. The research closed with a post-test for further evaluation.

11.4.3 Analysis

In analysing the data, we first looked for instances where the four L2L2 elements (distributed leadership, mutual engagement, peer assessment, group reflection) interact with the process of meaning generation. In addition, we looked for (a) the role of the domain in shaping the way shared understanding is constructed, (b) how the group collaboratively construct meaning and (c) what is the role of the Metafora System in shaping collaborative meaning generation. Finally, we examined how students use their constructions during the different stages of meaning generation and if they use them as representations of their ideas.

11.5 Results

11.5.1 The Interaction between L2L2 Elements and the Process of Meaning Generation

The aim of this line of analysis is to study the process of meaning generation in the context of L2L2 and elaborate on how L2L2 might influence (prevent, facilitate, etc.) the process of meaning generation. Specifically, students were asked to address a challenge: "Keeping the blue and the green balls still, shoot the red ball vertically upwards". S9 proposes to alter the magnitudes and some of them into zero and he insists in this opinion. S15 wants to select only the red one, another (S9) wants to control all the balls… (Extract 11.1).

Extract 11.1

S7: As in keeping the blue and the green ball steady
S9: How are we supposed to do that? Should we possibly alter a magnitude?
S15: I didn't really get what we are supposed to do
S7: Whatever is written in bold letters
S9: Yes, but should we alter some of the magnitudes into zero
S15: Yes, but this should be set for all of them
''How are we going to keep the green and the blue ball to the bottom" (LASAD: Question)
S9: Does anyone have the answer to this marvelous question?
S15: No
S9: I suggest we set the degrees into zero
S15:In juggler there are three circles, the red, the green and the blue. We are going to press the red one.
S9: Fine
S15: And are we going to leave the rest of them the way they are?
S9: But whether or not we had the red one selected, they were all moving
S15: Yes, because we had them all pressed
S9: Is this for sure?
S15: It said "red green and blue"
S9: Yes, but only the red one was selected

(continued)

S15: Guys, you know something, when the red ball was launched the tablet turned into red
S9: If we also selected the rest of them we could control each one individually
S9: Fine, we assume that we are able to control all of the balls
“We deem that we are able to control all of the balls” (Planning Tool: Make an hypothesis)

11.5.2 The Role of the Domain in Shaping the Way Shared Understanding

The fact that the issue under negotiation belongs to the scientific domain of physics is determinative in guiding and predefining the context of shared understanding since measures, variables and values will mainly concern their negotiations and aspect exchanges. A characteristic incident of domain prevalence in the discourse of the group members is the following: S15 wants to set the “shot altitude” into zero and S9 agrees and proposes the “power” as well. S7 reads in the research protocol about stillness and S15 concludes that “wind speed” and “wind direction” should be into zero (Extract 11.2). They use LASAD (Fig. 11.2) to elaborate on this problem-solving strategy and Planning Tool to reflect on this method (Fig. 11.3).

Extract 11.2

S15: Guys, we should set the altitude of the shot into zero
S9: And the “power” as well
S15: Good
S7: It says that there is stillness all around
S9: Yes, there is no wind
S15: Therefore “wind speed” and “wind direction” equals 0
S7: Hang on, the questions are leading us. Here says, into what value do you think “shot azimuth” should be set in order to move vertically upwards
S9: Wait a second, it says how do you think you can keep the green and the blue ball stationary…by setting “shoot azimuth”, “shoot altitude” and “power” into zero
“We assume that we are able to control all of the balls and each one of them individually by selecting it” (LASAD: Comment)
S9: Shouldn’t we also make the action plan?
“We set the direction of the shot, the altitude and the power applied to the balls apart from the red one into zero”(Planning Tool: Make an hypothesis)
S9: Afterwards we set “analyzing”
“In order for the red ball to move vertically, we set the value of “shot altitude” into 90” (Planning Tool: Analyze)
“ In order for the red ball to move we set to the rest of them “shot azimuth”, “shoot altitude” and “power” into zero, to the red one we set the value of “shot altitude” into 90” (LASAD: Comment)

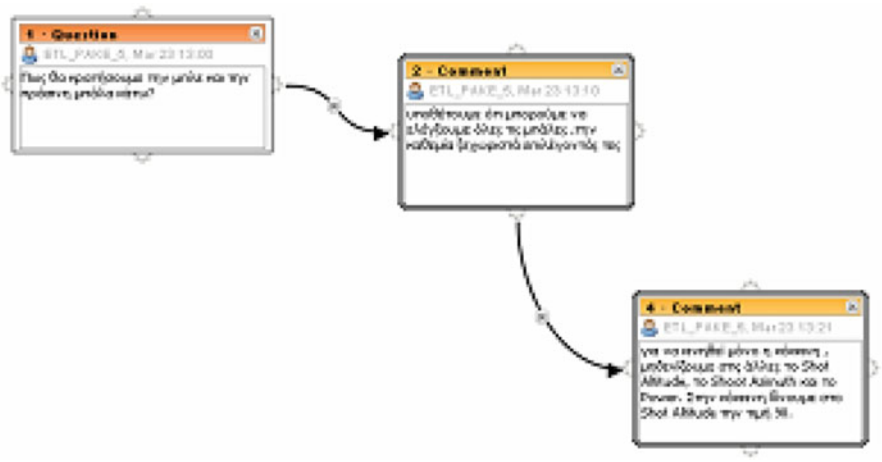


Fig. 11.2 The students used LASAD to elaborate on this problem-solving strategy

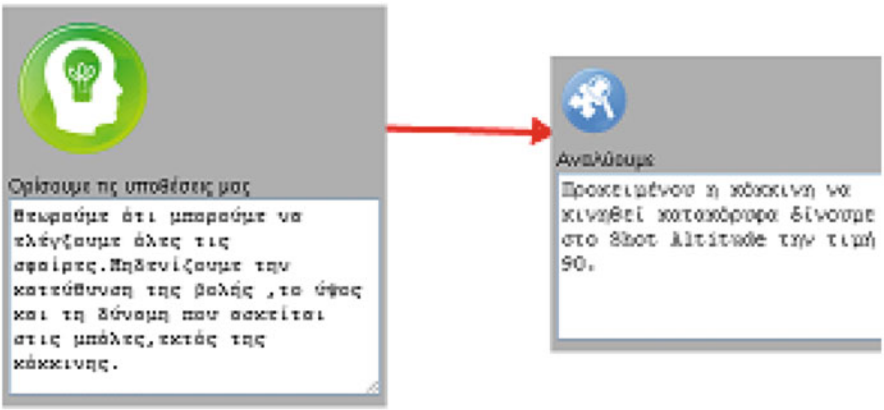


Fig. 11.3 The students used the Planning Tool to reflect on this method

The ENG[1] group had designed more rich plans in the Planning Tool and argumentation tool. In the Planning Tool, they used the cards: define questions, build a model, test a model, experiment, refine a model and some attitudes cards (Fig. 11.4). They decided to set all physical quantities in zero except for these that control mass and size for the green and blue balls. Using LASAD tool (Fig. 11.5), the (ENG) sub-group 2 shared its findings with the (ENG) sub-group 1 and they came to an agreement.

[1] One group of 4 volunteered to work using the Metafora platform's tools in English interface and to answer the questions in English (ENG group).

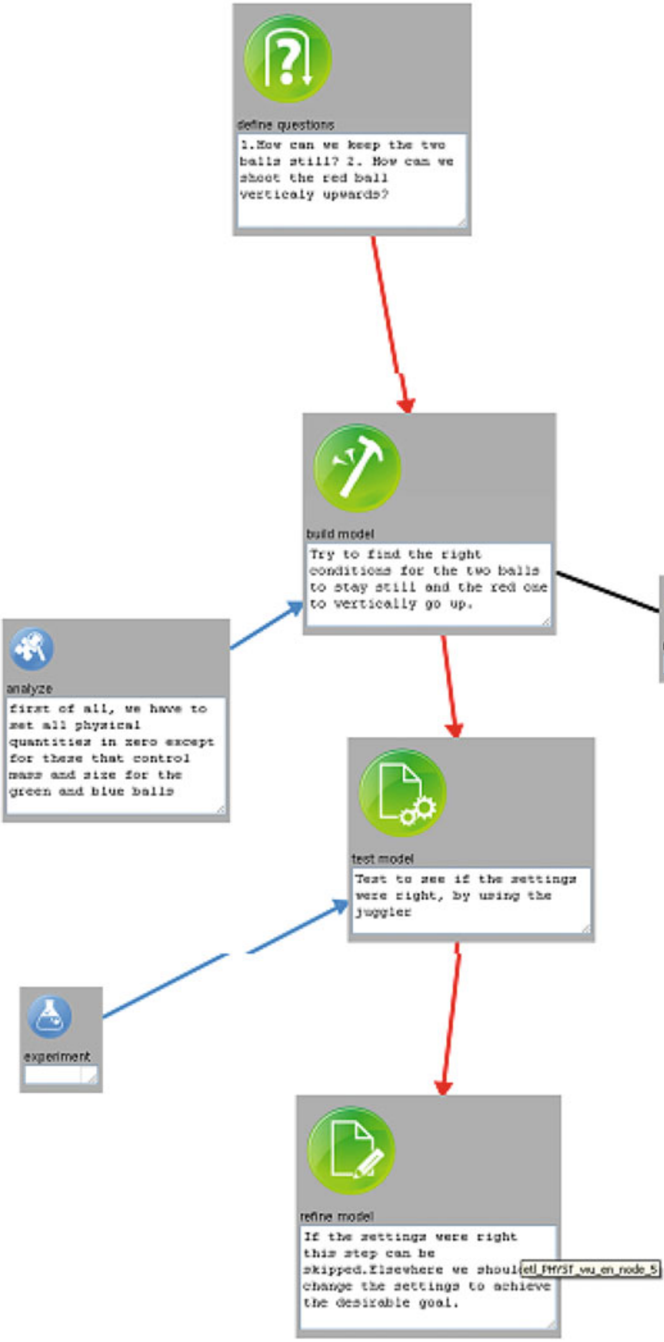


Fig. 11.4 The ENG group used the Planning Tool to reflect on this method

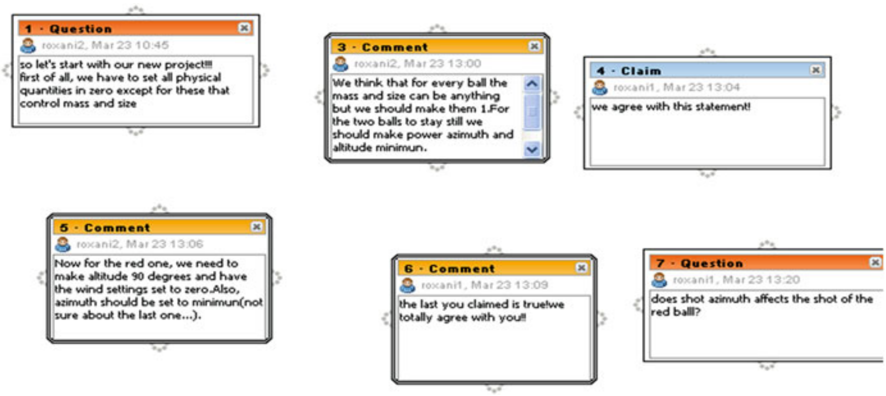


Fig. 11.5 The ENG group used LASAD to elaborate on this problem-solving strategy

11.5.3 Meaning Generation in Collectives

Meaning generation is accomplished in the context of expanding the space of dialogue by reflecting on assumptions and allowing space for more voices which suggest problem posing ideas into the dialogue. Disagreement on an issue – in the perspective of exploratory type of talk – might lead to a detailed analysis of the different aspects of a concept. Specifically, students must construct a map with the help of the Planning Tool, in collaboration with two people in the second subgroup, which will show the progress of Galileo and his disciples from the beginning until the foundation of the law of free fall. The students begin the construction of the plan, disagreeing between them. This disagreement leads them to a detailed analysis of the different aspects of inquiry process. More specifically, S7 suggests that they should start with the card "define our affairs." S9, however, observes that Aristotle was the one who appointed cases and Galileo was the one who challenged them. S7 states that Galileo did not challenge the assumptions of Aristotle, but rejected them having first experimented. He had some evidence from Aristotle on which he was based, but he didn't think it all by himself. S9 by making another suggestion says that Galileo, first analyzed the data of Aristotle, experimented with them and then assessed their effect. S7 agrees with his classmate, but says that they should add more things. S7 suggests that they should use the card "analyze" first and S9 agrees. Then S7 proposes that they should drag the "define our affairs" card on the Planning Tool but S9 disagrees. Then S7 explains that they should first make the case (Aristotle) and then to refute it by experiment (Galileo) to draw conclusions (Extract 11.3).

Extract 11.3

S7:Well, let's start defining the cases
S9:Yes, but Aristotle had posed the cases
S7:Exactly
S9:Yes but we want Galileo's plan, he didn't define a case, he questioned one
S7:Wait, he didn't question, he experimented, he denied after he had experimented
S9:Wait, so he experimented and then he denied
S7: First we say that he had some of Aristotle's data, so he thought and counted on that, it didn't come straight to his mind
S9: He didn't have an inspiration, what do you say about that he firstly analyzed it, he experimented and then he evaluated
S7: Not so easy, it's on right basis, but we can add more things, shall we write on the paper?
S9:We can't
S7: Firstly we analyze
S9: So yes bring out the card to analyze

11.5.4 The Role of the Metafora System in Shaping Collaborative Meaning Generation

The web-based environment, Metafora platform, gathers and makes use of purposeful tools for the activation of collaborative procedures particularly focused on generating meaning jointly based on common ground. A characteristic incident that denotes such a collaborative practice as induced by the Metafora System is the following: The students have described their disagreement in LASAD Map using only Comment cards (Fig. 11.6). Then, students transfer to LASAD and observe that the other sub-team has put at the Planning Tool desktop the "define our affairs" card first. Then they write on the chat system to respond to the other team: "you cannot pose any questions without information". After a while though, communication followed and they understood that it was possible since Aristotle had done it before.

The ENG group had no disagreement and they used attitude cards in their Galileo's plan (rational: Aristotelis, Critical: Galileo and his students). The collaboration between the two ENG sub-groups was perfect, which is projected in their LASAD Map (Fig. 11.6). The one sub-group put a question and the other responded or commented but they didn't use the arrows in their map.

11.5.5 Constructionism in Collectives

In the context of the web-based environment, Metafora platform, we examine a group of learners' constructions as they are addressing a number of scientific challenges. In physics, they use their constructions (models) as representations of their

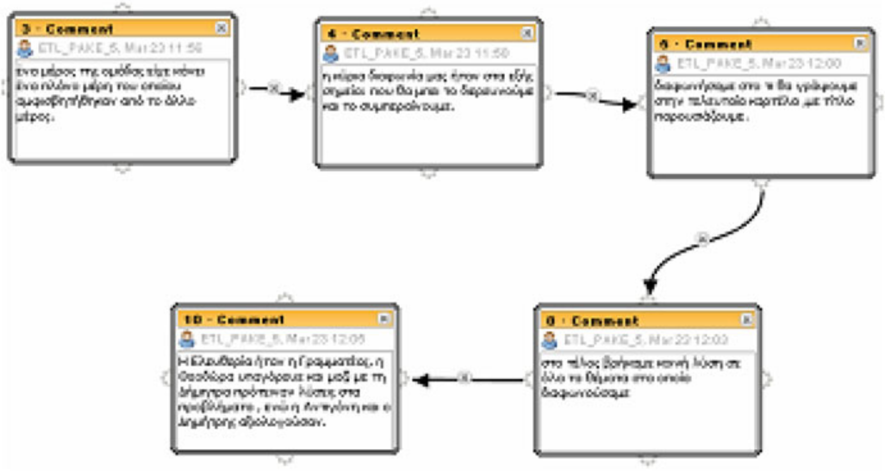


Fig. 11.6 The students used LASAD to express their disagreement elaborate

ideas, as objects that can be explored and challenged and as mediators for communication with other groups or other members of the group. The students collaboratively constructed multiple models – depicting initially intuitive ideas and as they proceeded they carried on elaborating on more systematic ones – and they tested them through visual feedback, which is an intrinsic feature of the microworld. Their actions are revisited again and again as they built models to test their ideas, simulated them to observe the visual result, discussed about them and rebuilt them according to their newly arisen understandings.

Specifically, from the collected data, we observe the mutual shaping of scientific meanings during the users' interaction with the representational background and functions of the implemented cognitive theory – structured and projected as a problem under negotiation – on the virtual imprinting at the interface of the microworld. In particular, the students interacting with the tool make the following findings: "S9: The first is the weight of the ball" and "S15: The altitude is the height." Also they realize the mutual shaping of meaning through the dynamic interaction of the user with the potential functions that microworld provides. This important impact of the tool for provoking and encouraging deeper access into the cognitive issue under negotiation appears characteristically in the following phrases: "S9: Yes, but should we alter some of the magnitudes into zero?" and "S15: Yes, but this should be set for all of them". In this case, we observe the role of technology as a means for setting a purposeful task to be pursued while at the same time it triggers a series of new arising issues to be explored and set under negotiation.

The phenomenology of the interface of the microworld as a reference during engagement of the user with the tool affects the construction and use. The problem under negotiation as it is instantiated on the screen should call for dynamic manipulation and thoughtful experimentation. Synergy of the tool and the multi-aspect perception of a collaborative group can result in successful meaning generation which is in situ produced and based on tangible proofs. Characteristic phrases of children which highlight the importance of the representational structure of the microworld as a stimulus for growing cognitive formats are: “S7: Run to see the result … ”, “S9: lower it because I see no difference … the first is the wind direction and the second is the speed but I do not see any difference in motion” and “S9: selected or not the red one, they were all moving”. In these three phrases, we follow the effort of students to solve the problem under negotiation relying on the virtual imprinting at the interface of the microworld.

Constructions are mainly used as boundary objects, as seen through the process of negotiating and cognitive transactions are undergoing between the members of the team while interacting with the microworld in order to construct a map of their own understanding of concepts. Characteristic phrases that children use during their effort to produce scientific knowledge and solve the negotiated problem or for the construction of their own structure (artifact), are: “S15: it measures the size of the ball but I do not know the scale” and “S9: Wait a minute … yes guys but how is power measured as percentage of force.” Other constructions are culmination of metacognitive skills cultivated among students while collectively trying to solve a problem. Characteristic phrases of children associated with constructions that pinpoint the metacognitive progress of students are the following: “S15: the acceleration of gravity, so the gravity pull is the acceleration of gravity, and the faster it grows the faster an object lands” and “S9: suppose that we can control them one by one, I think that if I reset this and that they wouldn’t move.”

Constructions are also perceived as improvable objects that regulate the collaborative activity and help build a shared understanding of the scientific concepts the group is dealing with. Users through a constructive negotiation of the underlying powerful Ideas are actively engaged in a procedure requiring and provoking meaning generation as a way for scientific self-explanation and verification in order for logically correct conclusions to be reached. Characteristic phrases of students’ cognitive process of reaching conclusions and improvement of constructions are the following: “S15: Guys, you know something, when the red ball was launched the tablet turned into red” and “S9: If we also selected the rest of them we could control each one individually”. Through this short exchange of discourse we see the measure of support provided by the construction by visualizing the thoughtful manipulations of the users and advocating in the creation of a shared understanding which will ultimately evoke new group cognitive contributions as well as their accompanied self-explanations.

11.6 Discussion and Conclusion

This article presented a specific case study in physics with the implementation of the Metafora web Platform as a shared workspace and a holistic environment in which students are triggered to engage in L2L2 and meaning generation processes. The study showed that the students collaboratively manipulated and created models of motions using the 3d Juggler and further communicated their ideas via the Metafora Platform's shared workspaces. In the research, it was shown that the Newtonian Physics microworld with its representational phenomenology acts as the common ground that supports the negotiation of the scientific concepts implemented in it whereas the web-based platform challenges and enhances students' mutual engagement in the exchange of cognitive perceptions and self-expressions of reasoning which inevitably lead to a better understanding of the scientific methodology and its application in a specific context according to logical procedures.

However, further research is needed to examine the impact of the application of the Metafora Platform while encompassing larger groups of students as well as different microworlds with implemented concepts from various disciplinary fields. It is of utmost importance to investigate whether the Platform's support concerning the L2L2 and meaning generation processes regarding Science Education will be of equal significance and efficiency when applied on different educational contexts.

Acknowledgements Metafora: "Learning to learn together: A visual language for social orchestration of educational activities". EC – FP7-ICT-2009-5, Technology-enhanced Learning, No. 257872.

References

1. Avouris, N., Margaritis, M., Komis, V., Saez, A., & Melendez, R. (2003b). Modelling space: interaction design and architecture of a collaborative modelling environment. In *Proceedings of 6th conference computer based learning in science (CBLIS), Nicosia, Cyprus* (pp. 993–1004).
2. Cooke, N. J., Salas, E., Kiekel, P. A., & Bell, B. (2004). Advances in measuring team cognition. In E. Salas & S. M. Fiore (Eds.), *Team cognition: Understanding the factors that drive process and performance* (pp. 83–106). Washington, DC: American Psychological Association.
3. Cobb, P., Confrey, J., diSessa, A., Lehrer, P., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13.
4. de Jong, T. (2006). Scaffolds for scientific discovery learning. In J. Ellen & R. E. Clark (Eds.), *Handling complexity in learning environments: Theory and research* (pp. 107–128). Oxford: Elsevier.
5. diSessa, A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155–1191.
6. Dragon, T., Mavrikis, M., McLaren, B. M., Harrer, A., Kynigos, C., Wegerif, R., & Yang, Y. (2013). Metafora: A web-based platform for learning to learn together in science and mathematics. *IEEE Transactions on Learning Technologies, 6*(3), 197–207.
7. Gressick, J., & Derry, S. (2010). Distributed leadership in online groups. *Computer-Supported Collaborative Learning, 5*, 211–236.
8. Hakkarainen, K. (2010). Communities of learning in the classroom. In K. Littleton, C. Wood, & J. Kleine Staarman (Eds.), *International handbook of psychology in education* (pp. 177–225). Bingley: Emerald.
9. Kynigos, C. (2007). Half–Baked Logo microworlds as boundary objects in integrated design. *Informatics in Education, 6*(2), 335–358.
10. Resnick, M., Maloney, J., Monroy-Hernandez, Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60–67.

11. Sherin, B. L. (2001). How students understand physics equations. *Cognition and Instruction, 19*(4), 479–541.
12. Smyrnaiou, Z., Moustaki, F., & Kynigos, C. (2011). METAFORA learning approach processes contributing to students' meaning generation in science learning. In D. Gouscos & M. Meimaris (Eds.), *Proceedings of the 5th European conference on games based learning (ECGBL)* (pp. 657–664). Athens: Academic Publishing Limited.
13. Smyrnaiou, Z., Moustaki, F., & Kynigos, C. (2012). Students' Constructionist Game Modelling Activities as Part of Inquiry Learning Processes. *Electronic Journal of e-Learning*, *10*(2), 235–248. Available online at www.ejel.org
14. Stahl, G. (2005). Group cognition in computer-assisted collaborative learning. *Journal of Computer Assisted Learning, 21*, 79–90.
15. Wegerif, R., & Yang, Y., (2011). Visual language for learning processes, Metafora Deliverable D2.1.
16. Wegerif, R., Yang, Y., De Laat, M., Pifarre, M., Yiannoutsou, N., Moustaki, F., Smyrnaiou, Z., Daskolia, M., Mavrikis, M., Geraniou, E., & Abdu, R. (2012). *Developing a planning and reflection tool to support learning to learn together (L2L2)*. Proceedings of IST-Africa 2012, Dar-es-Salam, Tanzania, May 2012.

Chapter 12
Using Physical and Virtual Manipulatives to Improve Primary School Students' Understanding of Concepts of Electric Circuits

Zacharias C. Zacharia and Marios Michael

12.1 Introduction

Research on science experimentation has been growing over the years. In fact, several studies have been conducted to investigate and document the value of experimenting through the use of physical manipulatives (PM; real world physical/concrete material and apparatus) and/or virtual manipulatives (VM; virtual apparatus and material which exist in virtual environments, such as computer-based simulations) in science (for a review see [4, 34]).

Given that both VM and PM were found to offer unique affordances to students when experimenting, many researchers have argued in favor of combining PM and VM [15, 26, 31, 34]. However, up until recently, a detailed framework depicting how PM and VM could be blended was proposed in the literature of the domain [15].

This framework takes into consideration the PM and VM unique affordances and specifically targets the content of each lab experiment separately. According to Olympiou and Zacharia [15], the PM and VM are blended and used in conjunction in the context of each experiment in a way that they match the needs of each experiment separately. This is the first time a framework suggests to target each experiment separately. Up until recently, researchers were assigning the use of PM or VM to a number of experiments before switching the mode of experimentation (PM or VM) (e.g., [5, 10, 24, 31]).

More specifically, the Olympiou and Zacharia [15] framework involves a series of steps that need to be followed in order to reach a fine blending of PM and VM. According to this framework, an educator or a researcher who is about to blend VM and PM for teaching purposes should take into consideration the overarching

Z.C. Zacharia (✉) • M. Michael
Research in Science and Technology Education Group, Department of Educational Sciences, University of Cyprus, 20537, Nicosia 1678, Cyprus
e-mail: zach@ucy.ac.cy; michaelm83@gmail.com

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_12

general learning objective of the experiments at task, students' prior knowledge and skills, the identification of the PM and VM unique affordances, the matched learning objectives with the corresponding PM and VM unique affordances, students' ability to switch manipulatives (PM to VM and vice versa), and researchers or teachers knowledge and skills (e.g., they need to know which PM and VM are available, how these PM and VM could be used, what affordances and limitations PM and VM carry, and whether their students have the knowledge and skills to use them) (for more details see [15]).

This framework has been tested successfully among undergraduate students [15, 16]. In particular, in these studies it was found that the use of a blended combination of PM and VM enhanced students' conceptual understanding in physics more than the use of PM or VM alone. However, no data are available concerning the effectiveness of this framework in enhancing the conceptual understanding of younger students. In fact, no unconfounded research study exists, at the primary school level, that examines how PM and VM could be combined for optimizing students' learning in science. Moreover, comparative studies concerning the use of PM and VM among young learners (i.e., Pre-K through K-6) is quite scarce [33, 35]. Therefore, the goals of this study was: (a) to examine comparatively the effect of using PM and VM (alone and blended) on primary school students' conceptual understanding, (b) whether any possible differences in the effect relate to the processes that students engage in during PM or VM experimentation, and (c) to investigate whether the use of blended combinations of PM and VM, which are created according to the Olympiou and Zacharia [15] framework, have a similar positive effect on primary school students conceptual understanding as it was the case with the undergraduate students.

For answering these questions, we followed the same research design as in our previous two studies [15, 16], in which three conditions were used (PM alone, VM alone, and a blended combination of PM & VM), but implemented them this time among primary school students. Finally, we situated this research design in the subject domain of electric circuits.

12.2 Theoretical Background

12.2.1 PM and VM Affordances

PM and VM have a significant overlap in terms of the affordances they could offer for experimentation purposes, such as the manipulation of material, the provision of direct observations, and the exposure to experimentation skills [6]. On the other hand, they carry affordances that differ. These differing affordances are what make PM and VM unique for teaching and learning purposes, and explain the need for using both in a leaning environment and selecting one of them over the other, according to which learning objective is better served by a PM or VM affordance.

In the case of PM, examples of such unique, advantageous affordances are the presence of touch sensory input, the acquisition of psychomotor skills, and the presence of measurement errors. Touch sensory input is advantageous because it was found to form the basis for conscious memory and learning [1, 11, 13]. Zacharia et al. [33, 35] concluded that touch is a prerequisite for science learning when it is the only modality that can provide the necessary sensory feedback for building knowledge related to the physical phenomenon being investigated and when the student does not already have this knowledge available from prior tactile experiences.

In conjunction with touch sensory input, students acquire and develop psychomotor skills, which are vital for interacting with the natural and human-made world. For instance, students using PM grab and heft with their hands for manipulation purposes, whereas basic VM users point, drag, and click with the mouse or touch the screen with their hands [26, 32].

A third example of a beneficial affordance of PM is the presence of measurement errors, which are usually ignored in VM environments. The reason behind the intentional absence of measurement errors in VM is to have students focus on the variables under study than the errors per se. In other words, the idea is to minimize the possibility of having the students being distracted when new concepts are introduced. This does not mean that the students won't focus on errors when experimenting. On the contrary, the idea is to do so right after they get a good picture of the newly introduced concepts. It is crucial for the students to experience measurement errors and acquire knowledge and skills in dealing with them because they are part of the world they are living in [24]. Moreover, measurement errors are an important reminder to the students that real life phenomena and systems are not perfect and that restrictive forces exist, such as friction, that affect their outcomes. Moreover, they reveal the "messy" nature of science and thus enable students understand the true nature of science [34].

In the case of VM, more unique, advantageous affordances exist. This is because VM were designed to surpass the inherent limitations of PM (which admittedly are many within the context of school science experimentation). Such unique and advantageous VM affordances are, the provision of the option for (a) allowing students to change variables, such as amplifying or reducing temporal and spatial dimensions, which are impossible to change in real life [27]; (b) using multiple dynamically linked representations at the same time [7, 17]; (c) allowing students to visualize objects and processes that are normally beyond perception [28] or conceptual/abstract in nature [17]; (d) receiving immediate feedback about errors and thus offering to the students the opportunity to fix the experimental set up immediately, which result in saving valuable experimental time [8, 20]; and (e) allowing students to perform a wide range of experiments faster and more easily and thus experience more examples within a given time framework [3, 8, 29, 30].

In the context of electric circuits, at the university level, it was found that the use of VM was more conducive to students' conceptual understanding than the use of PM, when certain unique VM affordances were present. Specifically, the VM affordances that were found to positively affect students' conceptual understanding were: (a) allowing students to visualize conceptual/abstract objects, namely the electron flow in electric circuits [5, 34]; (b) receiving immediate feedback about errors and thus offering to the students the opportunity to fix the experimental set up immediately [34]; (c) allowing students to perform a wide range of experiments faster and more easily and thus experience more examples within a given time framework [29, 30]; and (d) providing always observable outcomes, no matter how complex is the electric circuit [34].

Given these findings, it was also of our interest to examine whether these affordances could be found as beneficial to our primary school participants' conceptual understanding as it was for the students of prior studies at the university level.

12.2.2 *The Effect of PM and VM Experimentation on Primary School Students' Conceptual Understanding: Theoretical and Empirical Underpinnings*

The use of PM and VM for experimentation purposes more or less follows the same pattern across K-16. Students at all levels are expected to conduct an experiment, if not to design and set it up, as well. In this context, independent of PM or VM use, students are expected to identify the variables involved (e.g., which is the independent and dependent variables), form their hypotheses, alter the values of variables in a way that the experimental procedure is valid (i.e., run a fair experiment), observe the outcomes (the effect on the dependent variable), and initiate processes for taking data/measurements.

Given that PM and VM experimentation provide students empirical evidence through observations, researchers have argued about experimentation's potential to promote students' conceptual understanding at all levels [15]. Tao and Gunstone [23] characterized experimentation as a cognitive conflict model of instruction, because it allows students to make observations, compare these with their own (prior) conceptions, and attempt to reconcile any discrepancy between their conceptions and the observations from the experiment. In this way, PM and VM experimentation provide grounds for promoting conceptual change through *meaningful* cognitive conflicts and thus, enhance students' conceptual understanding (for details on how to achieve *meaningful* cognitive conflicts and conceptual change see [12]).

Research among primary school students, even though it is limited, has shown that experimentation through the use of PM alone and VM alone can enhance students' conceptual understanding in science (e.g., [2, 22]. However, for understanding how to combine/blend PM and VM, these studies are not very informative, because they do not reveal the relative value of each mode of experimentation (PM or VM) as opposed to the other. Comparative studies are needed in this respect, which examine the comparative effect of PM and VM on students' learning. From our literature review, we identified only three such studies [9, 10, 26], two of which concerned the subject domain of electric circuits at the primary school level [9, 10]. These latter two studies also involved a combination of PM and VM, which was parallel in nature (students were using first VM to conduct an experiment and then PM to conduct the same experiment).

Triona and Klahr [26] compared physical materials (springs, weights, and ramps in the transfer task) and virtual materials (a simulation with digital representations of the same materials) in the context of designing simple unconfounded experiments using the control of variables strategy. The sample comprised 92 fourth- and fifth-graders. The study carefully controlled for factors such as instructional format and adopted a range of outcome measures including: designing unconfounded experiments (student's understanding of the need to control variables), deriving correct predictions from these experiments, and making explicit reference to the need for experiments to be unconfounded. Both types of materials (PM and VM) were found to be equally effective in achieving these instructional objectives.

Jaakkola and Nurmi [9] examined whether combining PM and VM (first use VM to conduct an experiment and then PM to conduct the same experiment) would be more conducive to students' learning than using PM and VM alone. The sample of the study comprised of 66 elementary school students, who were placed into the aforementioned three conditions. The curriculum of the study focused on electric circuits. The results showed that the VM&PM condition led to statistically greater learning gains than the use of either PM or VM alone. There were no statistical differences between VM alone and PM alone. The authors highlighted the benefits of using in parallel VM and PM to promote students' understanding of electricity. Among others, they argued about the success of their parallel combinations that VM can help students to first understand the theoretical principles of electricity, whereas PM is necessary to challenge further students' intuitive conceptions by demonstrating through real life enactments that the theory discovered through PM applies in reality.

Along the same lines, the same research group [10] compared the learning outcomes of students using VM with the outcomes of those using VM in parallel with PM in the domain of electric circuits. Moreover, the authors examined how the learning outcomes in these environments are mediated by implicit (only procedural guidance) and explicit (more structure and guidance for the discovery process) instruction. The participants of the study were 50 elementary school students, who were randomly separated in the study's conditions: simulation implicit, simulation explicit, combination implicit, and combination explicit conditions. The results revealed that elementary school students can gain better conceptual understanding about electric circuits when they have an opportunity to use VM in parallel with PM than when using VM alone, even in the case when the use of VM is supported with explicit instruction.

Despite the encouraging results coming from the parallel use of VM and PM, this work [9, 10] has been criticized about the fact that the time-on-task was not controlled [15]. In particular, the critique focused on the fact that it is not possible to attribute the positive results on students' learning solely on the parallel combination of VM and PM, since the students in the VM&PM condition were repeating each experiment, which increased considerably their time-on-task (more than that of VM or PM alone users). Therefore, this critique brings us back to the fact that there is no solid framework in this research domain depicting how PM and VM could be combined in order to enhance students' learning. As mentioned in the Introduction, the purpose of this study, among others, was to shed light towards this direction.

12.3 Methodology

12.3.1 Participants

The participants were 55 sixth graders coming from three different classes of a public, primary school in Nicosia, Cyprus. The school is a typical public school that shares same demographics as most public primary schools in Cyprus. The sixth graders of the three classes selected from this school were also typical in terms of their performance in science compared to other primary schools. None of the students had a class on electric circuits before.

The students of all three classes/conditions were taught about electric circuits during their science classes by the same teacher for 3 weeks (80-minute periods per week). The teacher is a holder of two Bachelor's degrees; one in educational sciences and one in physics. Moreover, the teacher had a 6-year experience in teaching science at the primary school level.

The first class/condition involved the use of PM (PM condition, 18 students), the second class/condition involved the use of VM (VM condition, 18 students), and the third class/condition involved the use of a blended combination of PM and VM (PM&VM condition, 19 students) throughout the study.

The students in all conditions were randomly assigned to subgroups of three as suggested by the curriculum of the study [14].

12.4 Materials

The curriculum materials used were derived from the Electric Circuits module of the Physics by Inquiry curriculum [14] and adopted to serve the needs of sixth graders. In particular, we used material from Part A of the module of Electric Circuits of the Physics by Inquiry curriculum (pp. 382–454). Part A (Sections 1 and 2) involves only basic circuits, namely one- and two-bulb circuits, and targets the development of a qualitative, conceptual model for electric circuits in the context of one- and two-bulb circuits. In Section 1, the brightness of bulbs that are connected to a battery in different configurations is examined, and simple electric circuit concepts are introduced that will enable learners to account for relative brightness of the bulbs that they observe. In Section 2, students are encouraged to construct a conceptual model about the *behavior of electric circuits* from direct experience with batteries and bulbs.

In terms of the experimental material used, PM involved the use of physical objects [identical batteries, wires, switches, and resistive elements (e.g., bulbs)] in a conventional physics laboratory. The students were responsible for setting up their experimental set-ups (electric circuits) on their own. During PM experimentation, feedback was available to the students through the behavior of the actual system (e.g., bulbs' brightness).

In the case of VM, the Virtual Labs Electricity [19] was used. It was selected because it retained the features and interactions of the domain of Electric Circuits as

PM did, but also because it carried unique affordances that PM did not (e.g., it provided feedback when setting-up a circuit). In Virtual Labs Electricity, students were able to design and test any DC circuit mentioned in the curriculum by using the "same" instruments and circuit parts (batteries, wires, switches and resistive elements, such as bulbs) as when experimenting with PM. Circuits were created by clicking on icons representing electrical parts and moving the parts to the desired position in the circuit.

12.4.1 Data Collection

Data from four different sources were collected, namely a conceptual knowledge test, instructor's reflective journal, video data (including screen-captured data for all the VM conditions), and interviews. The conceptual knowledge tests were used to assess students' understanding, and the instructors' reflective journals and video data were used to gain insight into students' experimentation processes. The interviews were used for triangulation and clarification purposes. However, for the purposes of this paper we used only the video data and the data collected through the conceptual knowledge test.

12.4.1.1 Conceptual Knowledge Tests

The study's research design was a pre-post comparison study design. Thus, a test was administered to assess students' understanding of concepts concerning the electric circuits both before and after the study. The items included on the conceptual knowledge test were developed and used in previous research studies by our own research group. The test included seven open-ended items and took students about an hour to complete it. Five of them were paper-and-pencil items and asked conceptual questions, all of which required explanations of reasoning, and two of them involved a practical task, as well (students had to build the electric circuits in addition to answering questions about them on paper). The practical part of the latter two items were taken in the form of an interview and for each student separately (all students were videotaped). All items of the test consisted of subitems (each subitem corresponded to one question). We always required an answer and an explanation or reasoning for each subitem.

12.4.1.2 Video Data

For the purposes of this study, we randomly selected three groups from each condition for analysis of their discourse and actions in order to identify whether students engage in different processes during PM or VM experimentation. The selection of these groups was done after students completed the pretest. In particular, we randomly selected three groups per condition and compared their pretest scores to the scores of the remaining students in the same condition. This was to ensure that the students in the selected groups had similar levels of prior knowledge on electric circuits to the other student groups coming from the same condition. We used the Mann–Whitney test and found no significant differences across all comparisons ($p > .05$).

Video and audio data were collected from each group throughout the study. In the case of PM, we used camcorders, and in the case of VM, we used the screen-capture plus video–audio software (River Past Screen Recorder Pro) to capture actual computer work activity (e.g., actions, sounds, movements that take place on the computer monitor).

After capturing student discourse and actions for each of the selected groups of each condition throughout the study, we intentionally selected and analyzed only certain episodes that involved the critical events that interested us [18]. We watched the videos of the three conditions and identified the events in which a condition was diverting from the other conditions (e.g., repeating an experiment, arguing whether a circuit was built correctly). We then located and isolated the (video) episodes that included the experiments that involved these critical events (points of differentiation across the groups) and proceeded with transcribing the corresponding dialogues and with coding students' actions and activities. The idea was to check whether these instances of variation differentially affected students' discourse and actions and therefore also affected the students' processes in experimentation and their level of understanding of the electric circuits concepts introduced in these experiments. A total of about 270 min of student conversations were transcribed and coded. The corresponding actions of the students, within these 270 min of video, were also coded.

12.4.2 Data Analysis

12.4.2.1 Conceptual Knowledge Tests

The tests were analyzed both quantitatively and qualitatively. In the case of the quantitative methods, all participants' tests were first scored. The scoring of each subitem was performed through the use of a scoring rubric that included preset criteria (expected correct answer and expected correct explanation of reasoning), which were used to score whether the elements of the participant's overall response (answer and its accompanying reasoning) were correct. The scoring of the accompanying reasoning was based only on whether students provided specific concepts or evidence that were needed to support their answer, as prespecified in the scoring rubrics. A correct answer to a subitem received one point, and its corresponding reasoning was scored in accordance with how many of its preset criteria were met. Each prespecified concept or evidence present in the reasoning received a half point. However, it should be noted that students received points only when they provided a correct answer and a corresponding correct or partially correct reasoning. All tests were scored and coded blind to participant condition. We took the individual student as the unit of analysis.

The maximum score for each subitem varied according to the number of prespecified elements required to be present. However, the scales for the items on a test were about the same. Finally, all participants total scores were adjusted it to fit on a 100-point scale. An independent coder reviewed about 20 % of the data. The reliability measure (Cohen's kappa) for scoring of the conceptual knowledge test was .88.

The statistical analysis of the scored tests involved (a) one-way ANOVA for the comparison of the pretest scores of the three conditions, (b) paired samples *t*-test for the comparison of the pretest scores to the posttest scores of each condition, and (c) one-way ANCOVA for the comparison of the posttest scores of the three conditions on the study's test.

The qualitative analysis involved the identification and classification of students' Scientifically Acceptable Conceptions (SACs) and Scientifically Non-Acceptable Conceptions (SNACs) concerning current in the context of circuits that included up to five bulbs connected in series or in parallel. This analysis followed the procedures of open coding [21], in which the researchers first underlined the most important sentences in each student's pre- and posttest and marked keywords that characterized the student's conceptions with respect to *behavior of electric circuits* (e.g., which bulbs will and which will not, which will be the brighter bulb, why some bulbs are brighter than others). By comparing the sentences underlined and the keywords derived from the tests, the content-specific similarities and differences in students' test responses about the *behavior of electric circuits* were explored and summarized. Then, the researchers constructed qualitatively different subcategories of description, across rather than within the responses, that were used to classify the conceptions of *behavior of electric circuits*. By comparing the similarities and differences between the students of each condition, subcategories of conceptions emerged (for an example of such subcategory, see Table 12.2). The purpose of the open coding analysis was to reveal the subcategories of description that could characterize the qualitatively different perspectives in which *behavior of electric circuits* was conceptualized or experienced by the students of each condition.

In addition, the prevalence for each of the resulting subcategories was calculated, as well the mean frequencies and standard deviations of SAC and SNAC in the three conditions and on the study's test (see Table 12.3). The aim of the latter calculation was to compare whether students' conceptions changed over the course of the study. This procedure was essential because it clarified whether students with similar scores also shared the same ideas, either SAC or SNAC conceptions.

For internal consistency reliability purposes, a second independent rater reviewed about 20 % of the data. The reliability measures (Cohen's kappa) for identifying subcategories of SAC and SNAC as described above for the conceptual knowledge test was .84. The reliability measures (Cohen's kappa) for classifying students' conceptions according to the resulting subcategories was .91.

12.4.2.2 Video Data

For the video, audio and screen-captured data analysis, we also followed open coding from grounded research methodology [21] and took the group as the unit of analysis. In the case of the audio material, we transcribed the selected conversations and coded what the students were talking about (e.g., about the experimental setup, about their observations). After all transcribed conversations were coded and the list of codes was finalized, all coded transcripts were reviewed once more for consistency reasons. Interreliability data were collected as well. A second coder who did not have access to the first round of coding repeated the whole coding process. Cohen's kappa was calculated at .85. Differences in the assigned codes were resolved through discussion.

For analyzing the data related to what the students were doing with PM or VM, we coded the video and screen-captured data for students' actions (e.g., building a circuit, playing with the material, repeating an experiment). The codes emerged through open coding and aimed at capturing the students' actions during their work with the PM or VM. After the list of codes was finalized, all coded transcripts were also reviewed once more for consistency purposes. Interreliability data were collected as well. A second coder who did not have access to the first round of coding repeated the whole coding process. Cohen's kappa was calculated at .87. Differences in the assigned codes were resolved through discussion.

The analysis of these data involved contrasting the resulted codes for both discourse and actions and identifying the differences that existed among the three groups, over time. The idea was to discover when the three conditions deviate, if they deviate at all, and why. The purpose of such an analysis was to identify the cause behind any deviations found in terms of students' conceptual understanding.

12.5 Findings

12.5.1 Conceptual Understanding

The one-way ANOVA procedure indicated that the three conditions did not differ in pretest scores across all of the study tests, $F < 1$,ns. The paired samples *t*-test showed that all three conditions improved students' understanding of the electric circuits concepts at task after the study ($p < 0.001$ for all comparisons). However, the ANCOVA procedure revealed differences among the study's three conditions (for mean scores and *SD* on the posttest, see Table 12.1). Bonferroni-adjusted ($p < 0.01$) pairwise comparisons suggested that students' posttest scores in the PM alone and VM alone conditions were significantly lower than those of the students in the blended combination PM&VM condition. The pairwise comparisons did not show any significant difference between the students' posttest scores of the PM alone and VM alone conditions.

The qualitative analysis on students' conceptions (SAC and SNAC) revealed, for the category of *behavior of electric circuits*, a number of subcategories (for an

Table 12.1 Participants' mean scores and SD on the posttest

Condition	*N*	Mean	SD
PM	18	62	4.49
VM	18	65	3.55
PM&VM	19	87	6.28

Table 12.2 Example of a subcategory of student conceptions of behavior of electric circuits and the corresponding SAC and most prevalent SNAC

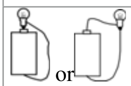
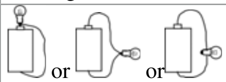
Category of conceptions	Example of sub-category of conceptions	SAC	Most prevalent SNAC
Behavior of electric circuits	Complete/closed single-bulb electric circuit	A complete single-bulb electric circuit is a circular, closed route arrangement of a bulb, a battery, and a wire, in which each of the two terminals of the bulb is connected with a different terminal of the battery (see the figures below). In this case, current is passing through all circuit elements and the bulb lights	A complete single-bulb electric circuit is a circular, closed route arrangement of a bulb, a battery, and a wire, in which one of the terminals of the bulb is connected with both of the battery's terminals (see the figures below). In this case, current is passing through all circuit elements and the bulb lights
			

Table 12.3 The mean frequencies and standard deviations of SACs and SNACs on the study's test in the three conditions

	PM&VM		VM		PM	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Conception type	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
SAC[a]	0.3 (0.3)	3.8 (0.6)	0.4 (0.2)	3.5 (0.5)	0.4 (0.4)	3.2 (0.7)
SNAC[b]	6.7 (0.8)	3.3 (0.9)	6.7 (0.6)	4.1 (0.7)	6.5 (0.6)	4.5 (0.9)

[a]SAC denotes scientifically acceptable conception
[b]SNAC denotes scientifically not acceptable conception

example of such subcategory, see Table 12.2), each of which included one SAC and a number of SNACs that students could hold.

Furthermore, the qualitative analysis on students' conceptions revealed that the PM alone and VM alone conditions shared about the same conceptions across the electric circuits concepts studied, as either SAC or SNAC, both before and after the study's test was administered. The PM&VM condition was found to share the same SAC and SNAC with the PM alone and VM alone conditions only before the study. After the study, the blended combination PM&VM condition had the highest prevalence for each SAC and the least for each SNAC. Table 12.3 shows the overall picture by means of mean frequencies of SACs and SNACs on the study's pre- and posttest in the three conditions. Overall, the results of the qualitative analysis confirm what was found in the quantitative analysis. On the pretest, very few students already possessed correct conceptions of the domain, and they displayed a variety of conceptions that were not scientifically acceptable. On the posttest, a higher number of correct conceptions could be seen than on the corresponding pretests, and in all cases, the number of SNACs found in the answers of the students went down. However, it is apparent that students in the PM&VM condition shifted from SNACs to the SACS to a greater extent than did those in the PM and VM alone conditions. This again is a result that is very much in line with what was found in the quantitative analysis.

12.5.2 Differences in the Experimentation Processes Followed across the Study's Conditions

For understanding the reasons, students' conceptual understanding was found to develop differentially between the PM&VM condition and the PM and VM alone conditions, we examined whether students differed in terms of the processes they followed during experimentation by studying our participants actions and discourse. In so doing, we used the video data.

Our analysis revealed a number of differences, which most of them were found to be VM dependent. First, VM students were found to set-up a circuit on the computer faster than PM students did on the lab bench. The VM affordance of receiving immediate feedback about errors (and thus offering to the students the opportunity to fix the experimental set up immediately) helped students in this respect. Second, VM students were found to repeat experiments easier and more frequently than PM students. We associated this with the VM affordance of faster manipulation, which allowed VM students to experience more examples. Third, VM students spend most of their discourse time more productively than PM. In particular, VM students were discussing more about the circuit at task and much less about process-related problems/issues (i.e., concerning the feedback received from the manipulatives used, particularly from PM [e.g., PM did not provide observable feedback in some circuits] and the problems faced when constructing complex circuits), as opposed to the PM students. The latter relates to the "messy" nature of science, which only PM students experienced. Despite the fact that experiencing the "messy" aspect of PM is vital for students to understand the true nature of science, in this case it affected negatively students work because the process-related problems distracted them from focusing on the conceptual aspects of the experiments. The affordance of providing always observable outcomes in VM environments, no matter what, have contributed in eliminating this problem among VM students.

The only difference found in favour of the students using PM was the fact that these students acquired and developed the psychomotor skills needed for setting-up a circuit in real life. This finding was also confirmed by the two practical questions of the test, which required from students to build circuits. The students of the VM alone condition were found to face problems in setting-up circuits in real life, because throughout the intervention, they did not get a chance to build physical circuits. On the other hand, besides the PM condition, the students of the blended combination did not face such problems because they also experienced building physical circuits through PM.

12.6 Discussion and Implications

In this study it was found that the use of a blended combination of PM&VM, according to the Olympiou and Zacharia [15] framework, was more conducive to sixth graders conceptual understanding of the electric circuits concepts than the use of PM and VM alone. This complies with the findings of the studies that made use of the Olympiou and Zacharia [15] framework at the university level for enhancing undergraduate students' conceptual understanding in Physics. Hence, it appears that the Olympiou and Zacharia [15] framework could successfully be used at the primary school level, at least with students similar to our participants and in the subject domain of electric circuits.

This study also points to the fact that blending PM and VM is better than using PM or VM alone, because this is the only way the unique affordances, which were found to be conducive to student learning, could co-exist in a learning environment. In this study, we have seen (a) the PM affordance of acquiring and developing psychomotor skills needed for setting-up a circuit in real life, to enable students learn how to set-up a physical electric circuit; (b) the VM affordance of receiving immediate feedback about errors during the construction of electric circuit, to support students in setting-up a circuit on the computer faster than PM students did on the lab bench, and thus increase their chances for more productive discussions (focusing on conceptual issues rather than on procedural issues); (c) the VM affordance of faster manipulation to provide students with opportunities for repeating an experiment easier and faster; and (d) the VM affordance of providing always observable feedback, which again enabled students to have more productive discussions, with the focus being on the conceptual aspects of an experiment rather than on the procedural ones. Interestingly, the same affordances were found to affect undergraduate students' conceptual understanding in physics, including in the subject domain of electric circuits [5, 29, 30, 34].

Needless to say, these findings also challenge the already established norms of teaching and learning through experimentation in the science classroom. Specifically, it challenges the laboratory experimentation as we experienced it through PM or VM alone, in a way that calls for its redefinition and restructuring [32], in order to include blended combinations of VM and PM [15]. For instance, one practical implication coming out from this study is that primary school students, who study electric circuits and the improvement of their conceptual understanding is at task, should be offered not only the use of VM, which allow better access to observations and less time for setting-up an experiment, but also the use of PM for acquiring and developing the necessary psychomotor skills for building electric circuits in real life. Restricting students to either the use of PM or VM is like stripping them from benefiting from the advantageous affordances of both modes of experimentation.

On the other hand, this call for reform creates the need for further research [5, 10, 25, 28, 32–34]. In particular, the Olympiou and Zacharia [15] framework or other similar frameworks need to be tested across different ages and subject domains, as well as wider sample sizes and different types of manipulatives. Given the increasing presence of computer technology in science classrooms, conducting research concerning VM and their relationship with PM is becoming an imperative need.

References

1. Bara, F., Gentaz, E., Pascale, C., & Sprenger-Charolles, L. (2004). The visuo-haptic and haptic exploration of letters increases the kindergarten-children's understanding of the alphabetic principle. *Cognitive Development, 19*, 433–449.
2. Bredderman, T. (1985). Laboratory programs for elementary school science: A meta- analysis of effects on learning. *Science Education, 69*, 577–591.
3. Carlsen, D., & Andre, T. (1992). Use of a microcomputer simulation and conceptual change text to overcome student preconceptions about electric circuits. *Journal of Computer-Based Instruction, 19*, 105–109.
4. de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*, 305–308. doi:10.1126/science.1230579.
5. Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Kohl, K. K., Podolefsky, N. S., & Reid, S. (2005). When learning about the real world is better done virtually: A study of substituting simulations for laboratory equipment. *Physical Review Special Topics: Physics Education Research, 1*, 1–8. doi:10.1103/PhysRevSTPER.1.010103.
6. Hofstein, A., & Lunetta, V. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*, 28–54.
7. Hsu, Y.-S., & Thomas, R. A. (2002). The impacts of a web-aided instructional simulation on science learning. *International Journal of Science Education, 24*, 955–979.
8. Huppert, J., & Lazarowitz, R. (2002). Computer simulations in the high school: Students' cognitive stages, science process skills and academic achievement in microbiology. *International Journal of Science Education, 24*, 803–821.
9. Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning, 24*, 271–283. doi:10.1111/j.1365-2729.2007.00259.x.
10. Jaakkola, T., Nurmi, S., & Veermans, K. H. (2011). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. *Journal of Research in Science Teaching, 48*, 71–93. doi:10.1002/tea.20386.
11. Klatzky, R. L., & Lederman, S. J. (2002). Touch. In A. F. Healy & R. W. Proctor (Eds.), *Experimental psychology* (pp. 147–176). New York: Wiley.
12. Limon, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*, 357–380.
13. Loomis, J. M., & Lederman, S. J. (1986). Tactual perception. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performances* (Cognitive processes and performance, Vol. 2, pp. 1–42). New York: Wiley.
14. McDermott, L. C., & The Physics Education Group. (1996). *Physics by inquiry*. New York: Wiley.

15. Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education, 96*(1), 21–47.
16. Olympiou, G., & Zacharia, Z. C. (2014). Blending physical and virtual manipulatives in physics laboratory experimentation. In C. Bruguière, P. Clément, & A. Tiberghien (Eds.), *Topics and trends in current science education* (pp. 419–433). Dordrecht: Springer. doi:10.1007/978-94-007-7281-6_26.
17. Olympiou, G., Zacharia, Z. C., & de Jong, T. (2013). Making the invisible visible: Enhancing students' conceptual understanding by introducing representations of abstract objects in a simulation. *Instructional Science, 41*, 575–596. doi:10.1007/s11251-012-9245-2.
18. Powell, A. B., Francisco, J. M., & Maher, C. A. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *The Journal of Mathematical Behavior, 22*, 405–435. doi:10.1016/j.jmathb.2003.09.002.
19. Riverdeep Interactive Learning. (2009). *Virtual laboratories electricity*. Retrieved from http://web.riverdeep.net/portal/page?_pageid=818,1382928,818_1382947&_dad=portal&_schema=PORTAL
20. Ronen, M., & Eliahu, M. (2000). Simulation a bridge between theory and reality: The case of electric circuits. *Journal of Computer Assisted Learning, 16*, 14–26.
21. Strauss, A., & Corbin, J. (1998). *Basics of qualitative research. Techniques and procedures for developing grounded theory*. Thousand Oaks: SAGE Publications.
22. Sun, K.-T., Lin, Y.-C., & Yu, C.-J. (2008). A study on learning effect among different learning styles in a Web-based lab of science for elementary school students. *Computers & Education, 50*, 1411–1422.
23. Tao, P., & Gunstone, R. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching, 36*, 859–882.
24. Toth, E. E., Morrow, B., & Ludvico, L. (2009). Designing blended inquiry learning in a laboratory context: A study of incorporating hands-on and virtual laboratories. *Innovative Higher Education, 33*, 333–344. doi:10.1007/s10755-008-9087-7.
25. Toth, E. E., Ludvico, L. R., & Morrow, B. L. (2012). Blended inquiry with hands-on and virtual laboratories: The role of perceptual features during knowledge construction. *Interactive Learning Environments*, 1–17. doi: 10.1080/10494820.2012.693102
26. Triona, L. M., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction, 21*, 149–173. doi:10.1207/S1532690XCI2102_02.
27. Windschitl, M. (2000). Supporting the development of science inquiry skills with special classes of software. *Educational Technology Research and Development, 48*, 81–95.
28. Winn, W., Stahr, F., Sarason, C., Fruland, R., Oppenheimer, P., & Lee, Y. L. (2006). Learning oceanography from a computer simulation compared with direct experience at sea. *Journal of Research in Science Teaching, 43*, 25–42. doi:10.1002/tea.20097.
29. Zacharia, Z. C. (2006). *Integrating real and virtual laboratory experimentation in an undergraduate physics learning environment*. Paper presented at the conference of the National Association of Research in Science Teaching, San Francisco, CA, USA.
30. Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning, 23*, 120–132. doi:10.1111/j.1365-2729.2006.00215.x.
31. Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. *Journal of Research in Science Teaching, 45*, 1021–1035. doi:10.1002/tea.20260.
32. Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. *Learning and Instruction, 21*, 317–331. doi:10.1016/j.learninstruc.2010.03.001.

33. Zacharia, Z. C., Loizou, E., & Papaevripidou, M. (2012). Is physicality an important aspect of learning through science experimentation among kindergarten students? *Early Childhood Research Quarterly, 27*, 447–457. doi:10.1016/j.ecresq.2012.02.004.
34. Zacharia, Z. C., & de Jong, T. (2014). The effects on students' conceptual understanding of electric circuits of introducing virtual manipulatives within a physical manipulatives oriented curriculum. *Cognition and Instruction, 32*, 101–158.
35. Zacharia, Z. C. (2015). Examining whether touch sensory feedback is necessary for science learning through experimentation: A literature review of two different lines of research across K-16. *Educational Research Review, 16*, 116–137. doi:10.1016/j.edurev.2015.10.001.

Chapter 13
Impact of Educational Video Game on Students' Conceptions Related to Newtonian Mechanics

Martin Riopel, Patrice Potvin, François Boucher-Genesse, and Geneviève Allaire-Duquette

13.1 Introduction

According to McGonagall [21], the average child in a country with a strong gamer culture will have spent 10,000 h playing online games by the age of 21, which is about the same amount of time spent in school. This gaming time is so huge that one can certainly ask if video games have a role to play in education. With 174 million gamers in the United States alone, we now live in a world where most probably every generation will be a gamer generation. Interestingly, 97 % of teenagers play with video games on a desktop computer, on internet, on a portable device or on a console [30].

Interactions with computers through educational video games is certainly one of the instructional strategy that has the potential of providing students with optimal learning experiences that take into account their misconceptions in mechanics while also fulfilling their need for interactive learning [29]. Today's "students are often viewed as digital natives [3, 23, 25, 26, 31] who prefer inductive reasoning, have high visual literacy skills, and require fast and frequent interactions with content" [2] (p. 348). Educational video games, because they place students in an active role [9, 11], give instantaneous feedback [11] and represent a good tool to change students' misconceptions [15] are a promising approach for renewing physics education.

Still, although the potential of educational video games as an efficient and appealing instructional strategy is well documented [3, 6, 28], games developed in universities generally fail to adequately integrate educational theories in a game format [17]. At most, their successes reported to be varying [13]. For example, in

M. Riopel (✉) • P. Potvin • F. Boucher-Genesse • G. Allaire-Duquette
Département de didactique, Université du Québec à Montréal, Montréal, QC, Canada
e-mail: riopel.martin@gmail.com; patrice.potvin@uqam.ca; francoisbg@ululab.com; allaire-duquette.genevieve@uqam.ca

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_13

the field of mechanics, many researchers acknowledge that even though there have been enough video games studies to show some potential, there is not sufficient evidence to prove their usefulness [27, 32].

Finally, while conceptual change has been the main focus of physics education research for at least 30 years, no theory on conceptual change has yet been sufficiently verified to be widely accepted [8]. Hence, it is of significant importance that research persists to examine how to efficiently generate long-lasting conceptual change.

The present study compares the learning outcomes of using an educational video game about Newtonian mechanics in class with teacher assistance (or at home without teacher assistance) to the learning outcomes of more conventional instruction by the same teacher in the same context. The learning outcomes are measured with the Force Concept Inventory [16], the most widely used test to assess student's conceptions about forces.

13.2 Background

According to Hays [13], in spite of the important number of papers published in the field of educational video games, most of studies express mainly opinions on the potential improvements they could bring to the classrooms. Consequently, any of them collected enough quantitative data to obtain significant and generalizable results. More specifically, there is only a handful of research about designing educational video games in mechanics. Four of them were identified and analyzed [4, 24, 26, 32]. A presentation of each of them can be found in Riopel et al. [28].

An overlook at Table 13.1 reveals that the precedent research designs in mechanics have some weaknesses, making them difficult to readapt or reuse for a new study. One can see, for example, that White's [32] and Rieber and Noah's [27] studies didn't use standardized tests to evaluate learning. Furthermore, even if Clark et al. [4] and Potvin et al. [24] did use the same standardized test, they failed to differentiate the game effect from the "teacher using the game" effect: Clark et al. [4] failed to differentiate because of the choice of research design, and Potvin et al.

Table 13.1 Comparison of existing EVG's research designs in mechanics

Studies	Sample Size	Standardized test	Teacher effect	Game effect	Combined effect	Rétention
White [32]	30			X		
Rieber and Noah (1997) [27]	70			X		
Clark et al. [4]	250	X		X		
Potvin et al. [24]	119	X	X		X	X

failed because inconclusive data. Considering that inconclusive results don't necessarily imply inexistent effect, it seemed important in the present study to compare again the learning outcomes when using an educational video game to at least one other instructional strategy.

Additionally, it seemed also important to experiment a game in the context where it is meant to be used: in a real class. As Hays [13] pointed out, an educational video game should also be integrated in a broader program and students should be asked to identify how it supports learning objectives. Consequently, as proposed by [10], discussions, lectures and other complementary instructional methods have been planned along with the game.

13.3 Mecanika

In the *Mecanika* video game, the player's goal consists of moving an object from point A to B using different types of robots with special powers. Students are invited to strategically plan their plays as they are rewarded with medals for succeeding at the first try. Moreover, if students understand how to use forces optimally, they get to 'recycle' the unused robots to unlock new game features. As the game environment includes at first gravity and friction, the challenges require that students progressively eliminate them with special robots. Finally, a colorful tail is drawn behind the moving object to help students visualize speed (the length of the tail) and active forces (the colors in the tail). This simple technique prevents students from being distracted by quantitative details like magnitude and units, while still giving them a sense of which kind of events are related to velocity shifts. *Mecanika*'s gameplay doesn't require any computation or any use of formulae. Extensive guidebooks complement the game and support the learning objectives.

Figures 13.1 and 13.2 present the actual first level of the *Mecanika* game. The goal is to place the wind robot in order to collect all stars with collect-o-matics (little robots). The collect-o-matics are not manipulated directly by the students. Instead, these students have to strategically place the big robots (controlling impulsion, wind, circular swing, gravity, maximum speed, etc.) to influence the trajectory of the collect-o-matics. The trick is to visualize the predicted trajectory and to place the robots accordingly. If successful, the collect-o-matics will pass over every star and the level will be completed. If the collect-o-matics fail to pass over every star, the robots will have to be reconfigured at different positions before another attempt is made. In the Fig. 13.1, the collect-o-matics fail to reach the third star because the wind robot (represented by the empty rectangle) has only been used partially. To successfully complete this level, the wind zone has to be placed in a way that optimizes its influence on the trajectory, as shown in Fig. 13.2, so that the collect-o-matics are accelerated over the full width of the wind zone, which allows them to pass over the ramp.

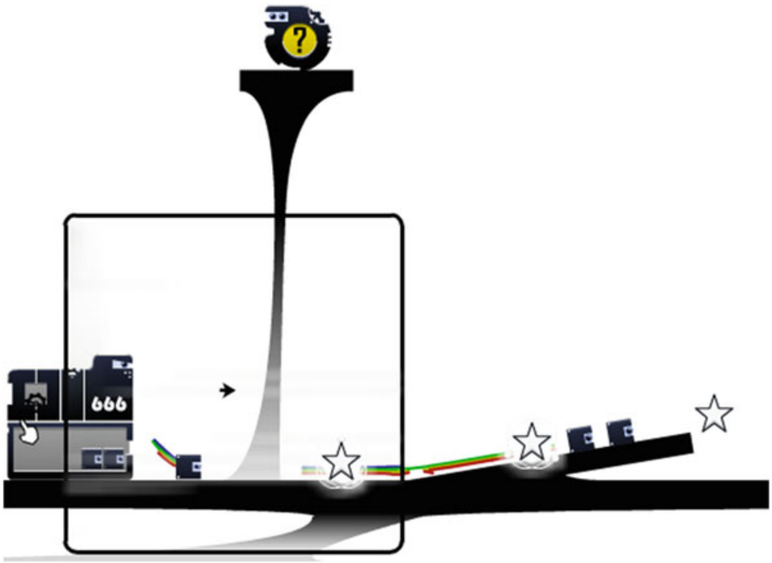


Fig. 13.1 *Mecanika*'s first level – wind robot partially used

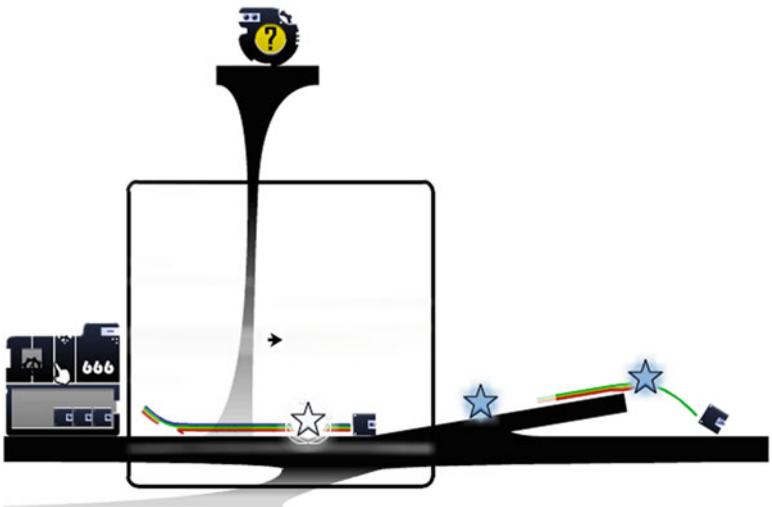


Fig. 13.2 *Mecanika*'s first level – wind robot optimally used

By using special robots in different situations, each of the 50 levels of *Mecanika* is designed to trigger a specific misconception in mechanics. Levels are grouped by themes which are commonly found in physics curriculums. Table 13.2 enumerates these themes and the related concepts.

Table 13.2 *Mecanika*'s set and associated concepts

Set	Theme	Mechanics concepts
A	Game's rules	Newtonian's laws
		Forces in equilibrium
B	Influence of impulsions on an object trajectory and speed, without gravitational force	Newtonian's laws
		Forces in equilibrium
		Uniform motion
C	Influence of continuous force and circular motion on an object trajectory and speed without, gravitational force	Newtonian's laws
		Forces in equilibrium
		Uniform motion
		Projectile motion
		Centripetal force
D	Influence of gravitational force and gravitational acceleration on objects of different mass	Newtonian's laws
		Forces in equilibrium
		Projectile motion
		Gravitational force
		Centripetal force
E	Inventory of active forces on an object	Newtonian's laws
		Forces in equilibrium
		Gravitational force
		Centripetal force
		Friction force

13.4 Research Design

The experimental study was set in 8 high school physics classes of high school. A total sample of 185 students was selected for the current study. Experimental group ($N=94$) received the treatment through *Mecanika* whereas the control group ($N=91$) was selected to receive conventional instruction. In the experimental group, students performed a sequence of homework with *Mecanika*, completed the study guide and discussed about the game in class. In the control group, after receiving conventional instruction with the same teacher for at most 3 months, the students performed only the *Mecanika* homework sequence in 1 month without any teacher assistance or instructions or study guide.

Data was collected using the Force Concept Inventory [16]. This is a validated multiple-choice questionnaire meant to probe students' conception of forces. It's the most widely accepted test in physics and, according to Huffman and Heller [18], it's also one of the most reliable. The suggested false answers are built around common misconceptions. The test was taken by students on line in the school's computer labs and lasted about 30 min. Force Concept Inventory was administered on both groups as pretest, posttest and then one month later as post posttest. The experimental plan is presented graphically in Fig. 13.3.

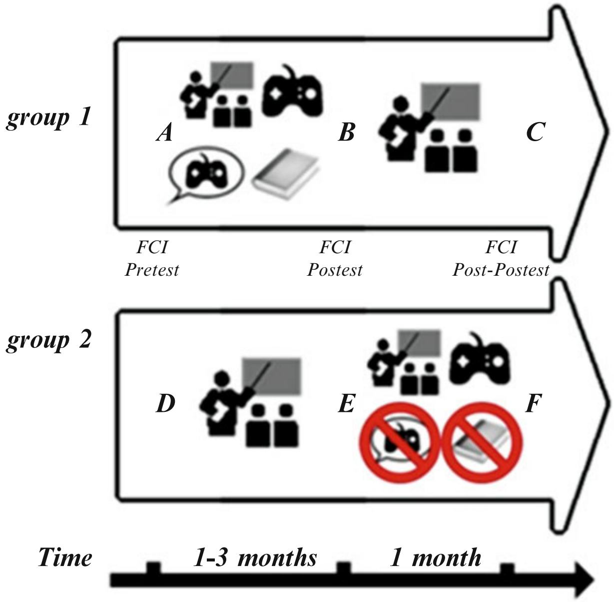


Fig. 13.3 Experimentation plan

As proposed by Hestenes and Halloun [15], normalized average gain was obtained by computing the ratio of the average gain on the maximum possible gain.

$$h = \frac{\%\text{post} - \%\text{pre}}{100 - \%\text{pre}}$$

Normally, after a complete traditional mechanics instruction, a group's average gain is $h = .25$.

13.5 Results

The researcher ran a *t*-test in order to compare the mean scores tests of the control and treatment group. Table 13.3 presents descriptive statistical results for the first part of the experimentation. Means and standard deviations are presented. The researcher predicted that students who received game treatment would outperform the control group. The average score of students for the pretest, for experimental and control group together, is 24.4 % ($N=185$) with a non-significant difference between groups that was still taken into account in the normalized gain.

On average, students that have being playing at *Mecanika* obtained a higher and significant ($p<.001$) normalized gain ($h=.10$, SD = .02) than students of control group that attended to a more traditional physics course ($h = .02$, SD = .02). An

Table 13.3 Results for the normalized gain between the pretest and the posttest

Group	*h*	SD	*df*	*t*	*p*	*d*
Exp.	.10	.02	84	6.73	<.001	1.0
Control	.02	.02	81	1.37	.175	0.3
Difference	.08	.02	165	3.81	<.001	0.6

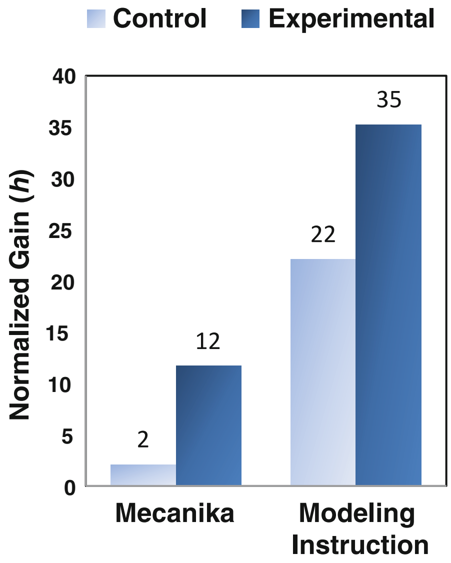


Fig. 13.4 Comparison of the gain associated with the *Mecanika* video game and the Modeling Instruction Project

independent samples test showed that the difference between the groups was significant $t(165) = 3.81$, $p < .001$ and of medium size ($d = 0.6$) according to Cohen [5].

For the second part of the experimentation, an independent sample test showed that the difference between the total gain for the control group that, after receiving conventional instruction, played at *Mecanika* without any assistance ($h = .08$, SD = .02) and the experimental group that stopped using *Mecanika* after the initial experimentation with teacher assistance and instruction ($h = .10$, SD = .02) was non-significant $t(145) = 0.70$, $p = .49$.

These results could denote a non-optimal design of guidebooks or of teacher's support, which would have diminished the gain generated by the use of *Mecanika* when integrated in teacher's planning. Another explanation could be that most of the game's potential to generate conceptual change comes with playing and not really with the verbal or written explanations that come with it.

The Modeling Instruction Project [12, 14] is more easily comparable with *Mecanika*'s experimentation since the tool for data collection was also the Force Concept Inventory. As presented in Fig. 13.4, Hestenes [14] obtained an average normalized gain of $h = 0.13$ which is comparable to the $h = 0.10$ obtained for *Mecanika*'s experimentation.

It is important to note that the *Modeling Instruction Project* was held over a whole semester while *Mecanika*'s experimentation obtained a similar gain on a much shorter time of intervention, ranging from 1 to 3 months. Also, the integration of the *Mecanika* video game to class didn't require much effort from teachers compared to Hestenes project which necessitated *an intensive 3-week Modeling Workshop that immerses [teachers] in modeling pedagogy and acquaints them with curriculum materials designed expressly to support it*. The explanations given to teachers for the use of *Mecanika* didn't last more than 30 min; considerably reducing the effort needed for implementation. The *Mecanika* educational video game is available freely at http://mecanika.ca.

13.6 Conclusion

This research found that there were significant differences among students' conceptual change with *Mecanika* as treatment. This study concurs with Martijn and Martijn [20] results and Almeida [1] findings that provide evidence that when games are used against the control group, significant increases in factual knowledge occur. The support of teachers and guidebooks didn't have a significant effect on conceptual change even if pedagogical guides were precisely designed to make the connection between the game and physics concepts. It thus seems that just playing the game, even without active involvement from teachers, can yield better learning outcomes than more traditional instruction. Based on the results of this research study, using educational games seems to be an effective way to design instruction for conceptual change. On a broad spectrum, result of this study advances the findings proposed by Hwang et al. [19].

13.7 Limitation/Further Research

Although this study statistically confirmed that subjects score higher on tests when game treatments are presented, there are several reasons to believe that the results of this research study could be biased. Even if students were asked to play at *Mecanika* as homework, only about half of them completed all the required levels. Consequently, results might be positively biased by the fact that the students who completed the required levels might be more motivated than the sample average. Also, a different integration of the game having a more structured discussion in class could generate different results. Finally, the positive results might be indicating the potential benefits of this genre of conceptually integrated games yet suggesting that further research and development will be needed to more fully harness this potential.

Acknowledgments The authors gratefully acknowledge the collaboration of the CREO company (http://www.creo.ca), and the financial support of the Social Sciences and Humanities Research Council (SSHRC), the Fonds de Recherche du Québec – Société et Culture (FQRSC), and the Canada Foundation for Innovation (CFI).

References

1. Almeida, L. C. (2012). The effect of an educational computer game for the achievement of factual and simple conceptual knowledge acquisition. *Education Research International, 2012*(961279), 1–5.
2. Anderson, J., & Barnett, M. (2011). Using video games to support pre-service elementary teachers learning of basic physics principles. *Journal of Science Education Technology, 20*, 347–362.
3. Annetta, L. A. (2008). Video games in education: Why they should be used and how they are being used. *Theory Into Practice, 47*(3), 229–239. doi:10.1080/00405840802153940.
4. Clark, D. B., Nelson, B. C., Chang, H.-Y., Martinez-Garza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring Newtonian mechanics in a conceptually-integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States. *Computers & Education, 57*(3), 2178–2195.
5. Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Mahwah: Lawrence Erlbaum.
6. Coller, B. D., & Scott, M. J. (2009). Effectiveness of using a video game to teach a course in mechanical engineering. *Computers & Education, 53*(3), 900–912. doi:10.1016/j.compedu.2009.05.012.
7. di Sessa, A. (2001). *Changing minds: Computers, learning, and literacy*. Cambridge: The MIT Press.
8. Di Sessa, A. (2006). A history of conceptual change research: threads and fault lines. In *The Cambridge handbook of the learning sciences* (pp. 265–282): Cambridge, MA: Cambridge University Press.
9. Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the "Cognitive Conflict" strategy for conceptual change – Some implications, difficulties, and problems. *Science Education, 74*(5), 555–569.
10. Egenfeldt-Nielsen, S. (2006). Overview of research on the educational use of video games. *Digital Kompetanse, 1*(3), 184–213.
11. Hake, R. R. (1998). Interactive-engagement vs traditional methods in mechanics instruction. *American Journal of Physics, 66*(1), 64–74.
12. Halloun, I., & Hestenes, D. (1987). Modeling instruction in mechanics. *American Journal of Physics, 55*(5), 455.
13. Hays, R. T. (2005). *The effectiveness of instructional games: A literature review and discussion*.
14. Hestenes, D. (2006). Notes for a modeling theory of science, cognition and instruction. In *Proceedings of the 2006 GIREP conference: Modelling in Physics and Physics Education*.
15. Hestenes, D., & Halloun, I. (1995). Interpreting the FCI. *The Physics Teacher, 33*, 502–506.
16. Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141–158.
17. Hopson, J. (2006). *We're not listening: An open letter to academic game researchers*, from http://gamasutra.com/features/20061110/hopson_01.shtml
18. Huffman, D., & Heller, P. (1995). What does the force concept inventory actually measure? *The Physics Teacher, 33*(3), 138–138.

19. Hwang, G. J., Wu, P. H., & Chen, C. C. (2012). An online game approach for improving students' learning performance in web-based problem-solving activities. *Computers & Education, 59*(4), 1246–1256.
20. Martijn, K., & Martijn, H. (2013). Conceptual change during a serious game. *Simulation Gaming, 44*(4), 544–561.
21. McGonigal, J. (2010). *Reality is broken, why games make us better and how they can change the world*. New York: Penguin Press HC. 400 p.
22. National Science Foundation's Panel on Cyberlearning. (2008). *Fostering learning in the networked world: Learning opportunity and challenge, a 21st century agenda for the National Science Foundation*. Arlington: National Science Foundation.
23. Oblinger, D. (2006). Games and learning: Digital games have potential to bring play back to learning experience. *Educause Quarterly, 3*, 5–7.
24. Potvin, P., Riopel, M., Charland, P., Ayotte, A., & Boucher-Genesse, F. (2010). *Enhancing performance in the "Force Concept Inventory" test using homework gameplay while involving physics teachers in the level design process*. East Lansing: SpaceFart.
25. Prensky, M. (2001). *Digital game based learning*. New York: McGraw Hill.
26. Prensky, M. (2006). *Don't bother me Mom, I'm learning!* New York: Paragon House Publishing.
27. Rieber, L., & Noah, D. (1997). *Effect of gaming and visual metaphors on reflective cognition within computer-based simulations*, Chicago, IL.
28. Riopel, M., Potvin, P., & Boucher-Genesse, F. (2015). Développement du jeu vidéo Mécanika conçu pour intervenir sur des conceptions identifiées au moyen d'un test standardisé. In J. G. Blais et al. (Eds), *Évaluation des apprentissages et technologies de l'information et de la communication* (pp. 151–169). Brussels: Peter Lang.
29. Squire, K. (2008). Video game-based learning: An emerging paradigm for instruction. *Performance Improvement Quarterly, 21*(2), 7–36.
30. Stevens, R., Satwicz, T., & McCarthy, L. (2007). In-game, in-room, in-world: Reconnecting video game play to the rest of kids' lives. *The John D. and Catherine T. MacArthur Foundation Series on Digital Media and Learning,* −, 41–66.
31. Van Eck, R. (2006). *Presentation at educause learning initiative annual meeting*. Paper presented at the Paper presented at the educause learning initiative annual meeting from http://www.educause.edu/upload/presentations/EL1061/FS04/Van%Eck.swf
32. White, B. Y. (1984). Designing computer games to help physics students understand Newton's laws of motion. *Cognition and Instruction, 1*(1), 69–108.

Part III
Teaching and Learning in the Light of Inquiry-Learning Methods

Introduction

The third part of this book is called 'Teaching and Learning in the light of Inquiry-Learning Methods'. The contributions address this theme by elaborating on the potentials of the inquiry-based teaching approach and presenting challenging contexts for its implementation in science and technology education. New perspectives and emerging issues arise that address unknown aspects and methodologies of inquiry-learning approach. Creative strategies, hands-on experiences, authentic contexts, webinars and shifting of the science classroom realities are some of the issues that chapters address in order to inform us on innovative strategies that apply to inquiry-learning approach.

The chapter *New Competences to Develop in Students to Help Them Get Involved in Sustainable Development while They Learn through Inquiry Methods* elaborates on the goal of acquiring sustainability competences. More specifically, in a world which faces urgent and complex problems, it appears necessary for students to develop key competences, such as critical, systemic, and futures thinking, creativity, problem solving, adaptability, ecological awareness, and so on, in order to help them become educated citizens of tomorrow with the capacity to comprehend the problems of the society, while being able to contribute to the development of a sustainable future with the characteristics of resources economy and collaboration.

CREAT-IT: Implementing Creative strategies into Science Teaching regards the issue of the introduction of creativity in the teaching of science. According to the authors, in order for this change to occur in schools, individual teachers need to be aware of the weaknesses of their practices, motivated to implement changes, and able to understand the best practices. The main focus of the CREATE-IT project is the implementation of teaching practices which integrate science teaching with creative disciplines, aiming at the motivation and enhancement of innovation.

The next chapter entitled *The PATHWAY to Inquiry-Based Teaching – European Perspective to Shift Science Classroom Realities* explores the field of inquiry-based teaching and presents a framework for the implementation of such a teaching practice. The authors claim that the specific framework allows the building blocks of subject-domain independent educational scenarios which apply specific inquiry educational approaches. Furthermore, it provides opportunities for both the implementation of existing best practice educational scenarios and the creation of new inquiry-based activities for science teaching.

The chapter *Pedagogy as an Inquiry Approach to Teaching: Inspiring Science Educators through CPD Webinars* reports on the ways upon which the Centre for e-Innovation and Workplace Learning at Dublin City University (DCU) provides teachers with a community of practice in order for them to examine their professional practices. The paper elaborates on the aim of the EU 'Inspiring Science Education' (ISE) project to provide teachers with the necessary resources to make science teaching relevant to students' lives. The authors make an account of the use of webinars to help science teachers implement an Inquiry-Based Learning (IBL) approach with the support of e- tools.

Chapter 14
New Competences to Develop in Students to Help Them Get Involved in Sustainable Development While They Learn Through Inquiry Methods

Diane Pruneau, Jackie Kerry, and Joanne Langis

14.1 Introduction

Humanity is facing social, economic, cultural and environmental changes that, in the long run, will endanger its survival. These changes are economic globalization, quick access to information, the need to deal with complexity and uncertainty, immigration waves and the growing gap between North and South. Our Earth is broken, sold and pillaged [10]. These changes require profound societal transformations. As the twenty-first century begins, two types of development coexist: global capitalism and a sustainability movement in various areas.

Sustainable development is a concept that is difficult to grasp. Its nature, significance, importance, players and the actions that ensure its attainment are beginning to emerge [20]. Its definition has evolved. Initially, it was seen as the use of resources and the environment to meet our current needs without compromising the needs of future generations [36]. Later, it was defined as a cultural adaptation made by society as it becomes aware of the emerging necessity of non-growth [5]. Next, it was perceived as a process for planning flexible, wise, long-term development to avoid destroying the very resources that keep us alive [17]. More recently, we encountered the possibility of humans and other species thriving on Earth forever [7]. Through all of these definitions we see that sustainability is not an end in itself, but a dynamic process that requires resilience and an ability to manage resources wisely in order to adapt to changes [1]. Sustainable development cannot be implemented in a single day, rather we hear more and more about a transition toward sustainability [18].

D. Pruneau (✉) • J. Kerry • J. Langis
Faculté des sciences de l'éducation, Université de Moncton, Moncton, NB, Canada E1A 3E9
e-mail: diane.pruneau@umoncton.ca; jackie.kerry@umoncton.ca; langisj@umoncton.ca

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_14

14.2 Sustainability Competences

Competence refers to a set of cognitive and metacognitive (knowledge, know-how, knowledge to act); conative (motivation to act), physical, social, spatial (efficient use of space), temporal (relevant organization of time), material (use of software) and affective resources and practices [13]. The field of sustainability competences developed because of complex current and future problems: climate change, desertification, pandemics, etc. There is no immediate solution for these complex, interrelated, urgent problems located in areas undergoing transformations and where there are strong probabilities of damage [34]. To solve these open problems, to take advantage of opportunities, to become agents of change and transition managers, students must develop key sustainability competences (i.e. cognitive, affective and motivational dispositions that enable them to bring changes in current economic, ecological and social practices without necessarily being changes in reaction to current problems) [6]. These key competences for sustainability, distinct from the general competences taught in schools, are associated with a vision of the world that is environmental, humanist and transformative. They enable citizens to understand the challenges faced by society and facilitate society's movement toward a sustainable future.

14.3 Objectives of the Study

At the international level, there is still little consensus regarding the key sustainability competences that should be developed in students [26]. In this article, we first summarize the recommendations by researchers relative to these competences. For our literature review we consulted scientific articles, books and reports. We also used the following databases: ERIC, ProQuest Dissertations and Theses, ABI/INFORM Global, PsycINFO, ACM Digital Library, ProQuest, SCIRUS and SAGE Journals. The keywords, alone or in combination, were twenty-first century competences, science skills and sustainability competences. In this article, we synthesize our analysis of the Canadian science and technology curricula for primary schools to identify key sustainability competences. The middle school level curricula in science and technology for each province and territory in Canada were analysed by two researchers. In Quebec, the curricula consulted were those of grade 6 and secondary 1 and 2, and elsewhere we consulted those of grades 6, 7 and 8. These grade levels were selected to show the learning results desired for students by the end of primary school. In addition, only the objectives of the curricula were analysed, and not the textbooks used to reach these objectives.

14.4 Key Sustainability Competences

14.4.1 Systems thinking

Systems thinking is the ability to analyse and represent complex systems and problems across different fields (society, environment, economy) and on various scales (local, global), while considering the cascade effect, inertia, retrospective effect and other controversial aspect of sustainability [23]. Systems thinking makes it possible to have an overall view of a situation, with its details, which are necessary to understand how a system works and the interdependent linkages between these elements [8]. We need only consider the variables, functions, subsystems, chains of cause and effect, and possibilities of resilience and adaptation [23]. Systems thinking includes understanding, empirical testing and structuring the controversies, their key components, their dynamics and the interconnection between human and natural systems [4]. This intimate understanding of the internal structure and of the dynamics of socioecological systems is required to identify where intervention is needed, to anticipate the future and to plan transition processes [34]. Complementary competences for systems thinking are linking thinking (ability to weave links between the elements of a system [29]) and solving complex problems.

14.4.2 Futures Thinking

Futures thinking consists in an ability to collectively build, analyse and evaluate detailed ideas of the future as they relate to specific situations [11, 12]. This approach sees not one, but several possible futures [26]. Images of the future involve qualitative and quantitative information, stories and visualizations [34]. The ability to foresee images requires competences in creativity and imagination [34]. Building images of the future takes into consideration time (past, present, future in the short and long term), continuity, non-linearity, probability, desirability, plausibility, uncertainty, risk and precaution [35]. It is important to develop futures thinking because sustainability requires thinking in the long term, anticipating dangerous consequences and seeking intergenerational equity. This ability makes it possible to develop various action options according to current conditions, and to identify potential opportunities and risks [6]. In sustainable development, it is important to see the future as something that can be shaped. Futures thinking is a source of empowerment and hope because we realize that the future can be changed [4]. Competences that complement futures thinking are risk prediction [24], decision-making [32] and hindsight (thinking about a past situation [15]).

14.4.3 Strategic Action

Strategic action is the ability to act and more specifically to initiate and manage change [2]. With respect to sustainability, the idea is to change the systems, structures, processes, ways of thinking, practices [19] and socially valued elements [14] to shape the future [33] and create alternatives to the complex problems of this postindustrial world [19]. Strategic action is the ability to plan collaboratively and to implement and evaluate interventions, transitions and governance strategies that move us toward sustainability. Such a skill involves understanding strategic concepts such as intention, inertia, obstacles, project leaders and partnerships. Setting goals and formulating measurement indicators are also necessary in this process, as well as knowledge of action strategies, sustainability, feasibility, efficiency, challenges, social movements and unwanted consequences [9]. Knowledge regarding methods of design, implementation, evaluation and adaptation of policies, of action plans (including several players) and of facilitating many perspectives are also needed. Plans must be flexible and capable of adapting to changing conditions and new knowledge that emerges while the action is taking place [6]. Strategic action is a useful competence because efforts toward sustainability imply the co-construction of knowledge and solutions [34]. A complementary competence to strategic action is collaborative planning in uncertain circumstances which presupposes consideration of side effects and any unexpected events that may occur while the action is taking place [24].

14.4.4 Interpersonal Competences

Interpersonal competences are the skills needed to motivate and facilitate attaining objectives related to sustainability and environmental problem-solving [30]. These competences also make it possible to understand other people's feelings, motivations, habits and aspirations [21]. Such competences demand familiarity with different kinds of collaboration and their dynamics [14]. The idea is to learn within and between organizations. Interpersonal competences include advanced skills in communication, deliberation, negotiation, collaboration, leadership, intercultural and interdisciplinary thinking, conflict resolution and empathy [30]. These skills are crucial because the challenges of sustainability are caused and influenced by the multiple players involved who have different experiences, resources, perspectives and preferences. Solving environmental problems and creating opportunities requires collaborating and negotiating with many players, scientists and the public [34].

14.4.5 Design Thinking

Creativity is necessary to change systems, structures, processes, ways of thinking and practices that have led to the problems we face today [19, 31]. It is also useful for changing oneself [19] and for creating alternatives for the complex problems of our postindustrial world [19]. Creativity in a world of rapid and unpredictable changes allows people to face new challenges [30]. In the field of creativity as applied to the environment, a new type of thinking is now introduced: design thinking. This is a creative and collaborative way of working in which intuition has an important role, solutions are abundant, testing of prototypes happens quickly, failures are interpreted as lessons and, mostly, consumers' needs are taken into consideration [16]. At the beginning of the twenty-first century, the company IDEO developed a problem-solving approach called design thinking. Since, this innovative approach, adopted by numerous companies (including IBM), has made it possible to generate original products: technological applications and interfaces; and fashion, architecture, scientific and engineering products. There are two types of design or processes thanks to which objects are created to solve problems. Designs can be traditional and call on inductive and deductive reasoning. These designs allow people to solve simple and closed problems, such as the position of a star during a particular period of the year. However, to solve complex problems, like finding climate change adaptations, another type of thinking is required: abductive thinking (thinking of a product that *could* exist). Design thinking is a new approach that applies the sensitivity and methods of designers to solving complex problems.

14.4.6 Ethical Competence

Ethical competence is the ability to collectively map, specify, apply, reconcile and negotiate sustainability values, principles, goals and objectives [34]. It is the ability to evaluate the unsustainable state of socioecological systems and to create sustainable versions of these systems by taking into consideration the concepts of justice, equity, socioecological integrity, safety, happiness, accountability and ethics [34]. Ethical competence implies a sensitivity that invites to self-reflect [26] and extend solicitude and preoccupations beyond personal and immediate needs into a feeling of solidarity with other people, locations and remote species [28]. This ability is useful because values and standards are interwoven into the concept of sustainability and, in this field, we seek to develop socioecological systems so that economic activities and environmental resources may be balanced or even improved [27].

14.4.7 Other Sustainability Competences

Other competences were revealed in our literature review. Critical thinking, for example, enables the assessment of one's values, actions, conceptions [26] and encourages thinking about current worldviews [10]. Critical logic and reasoning are also used to identify advantages and disadvantages of alternatives to solutions or approaches. Ecological awareness is defined as being open to interconnection, interdependence (between people, society, economy, culture and environment), diversity and wholeness of everything that exists [18]. Adaptability consists in an ability and a willingness to manage new and uncertain situations, including learning new tasks and procedures. When change arises, one should analyse new facts, identify ways of managing these facts and develop response strategies [3]. Finally, we found knowledge regarding sustainability: knowledge on the world and how it works; on natural capital (resources and services provided by nature); on human capital (individuals' intelligence and health); on social capital (social groups); on manufacturing capital (existing material and infrastructures); and on financial capital (money and the value of resources) [22].

14.5 Sustainability Competences in Canadian Science and Technology Curricula in Middle Schools

The analysis of Canadian science and technology curricula in middle school (grades 6–8) shows two pedagogical approaches in common: inquiry (socioconstructivist process that ends with the answer to a scientific question) and technological problem solving (which leads to a product or a structure for improving a situation) [25]. These curricula mainly target traditional competences attributed to scientists: formulating hypotheses, experimenting, collecting data, measuring, observing, etc. Sustainability competences appear very rarely in science curricula except for creativity and planning, which are more or less highlighted, in the solving technological problems approach. A certain amount of ecological awareness is also sought after in most curricula, but there is little use of systems, connective or futures thinking and of strategic action. With respect to problem solving, the complexity and interdisciplinarity of problems are barely addressed, as they would be if systems thinking were the learning goal. Students are invited neither to draw connections between the various elements of a problem nor to systematically predict the risks involved in these problems. The action for solving the problems studied is also barely present in the curricula objectives, depriving students from the opportunity to learn about the mechanisms related to action. Neither do curricula teach adaptability, which is an essential competence in case of disasters. Finally, knowledge regarding sustainability is hardly present.

It may be possible to enhance Canadian science and technology curricula in middle school in order to incorporate some key sustainability competences. A few steps could be added to the inquiry approach, already present in these curricula, in order to include new competences. When it comes time to pose the problem that needs to be solved, systems and connective thinking could be fostered by asking students to think about the problem from an interdisciplinary perspective, overall, from various cultural viewpoints, and to establish connections between the elements of the problem. To develop futures thinking and risk prediction, problem definition is a good activity in which to ask students to predict various scenarios of the future. During the solution-finding process, creativity could be systematically encouraged as well as decision-making and critical thinking in order to choose an efficient solution. The inquiry approach should add an action stage that aims to improve the problem being studied in order to put into practice planning and strategic action. For its part, the approach of technological problem solving, also promoted in these curricula, could be improved by having teachers apply design thinking by asking students to make original objects that meet human or ecological needs, in order to improve the quality of life of Canadians or of the environment. Some products, invented in the course of this approach, could lead to creating small businesses managed by students in which they could develop their planning and strategic action competences.

14.6 Conclusion

More studies must be conducted to further our knowledge regarding the choice and understanding of key sustainability competences. The pedagogical strategies which are most likely to support the development of sustainability competences among middle school students should also be investigated, as well as how to incorporate these competences into the current science and technology curricula.

Acknowledgements The authors thank the Social Sciences and Humanities Research Council (SSHRC) and the Natural Sciences and Engineering Research Council (NSERC) for contributing to this study.

References

1. Berkes, F., Colding, J., & Folke, C. (2003). *Navigating social-ecological systems: Building resilience for complexity and change*. Cambridge: Cambridge University Press.
2. Breiting, S., Hedegaard, K., Mogensen, F., Nielsen, K., & Schnack, K. (2009). *Action competence, conflicting interests and environmental education*. Copenhagen: Aarhus University.
3. Bybee, R. W. (2009). The BSCS 5E instructional model and 21st century skills. http://itsisu.concord.org/share/Bybee_21st_Century_Paper.pdf. Visited 8-Jan-2014.
4. Crofton, F. (2000). Educating for sustainability: Opportunities in undergraduate engineering. *Journal of Clean Production, 8*(5), 397–405.
5. Daly, H. E. (1993). Sustainable growth: An impossible theorem. In H. E. Daly & K. E. Townsend (Eds.), *Valuing the earth: Economics, ecology, ethics* (pp. 267–273). Cambridge: MIT Press.

6. de Haan, G. (2006). The BLK «21» programme in Germany: A «Gestaltungskompetenz»-based model for education for sustainable development. *Environmental Education Research, 12*(1), 19–32.
7. Ehrenfeld, J. (2008). *Sustainability by design: A subversive strategy for transforming our consumer culture*. New Haven: Yale University Press.
8. Erickson, H. L. (2007). Concept-based curriculum and instruction for the thinking classroom. Thousand Oaks: Corwin Press.
9. Grunwald, A. (2007). Working towards sustainable development in the face of uncertainty and incomplete knowledge. *Journal of Environmental Policy Plan, 9*(3), 245–262.
10. Hampson, G. P. (2012). Ecological education for the long emergency. *Futures, 44*, 71–80.
11. Hicks, D. (2006). *Lessons for the future: The missing dimension of education*. Victoria: Trafford Publishing.
12. Inayatullah, S. (2007). *Questioning the future: Methods and tools for organizational and societal transformation*. Tamsui/Taipei: Tamkang University Press.
13. Jonnaert, P., Barrette, J., Boufrahi, S., & Masciotra, D. (2004). Contribution critique au développement des programmes d'études : compétences, constructivisme et interdisciplinarité. *Revue des sciences de l'éducation, 30*, 667–696.
14. Kearins, K., & Springett, D. (2003). Educating for sustainability: Developing critical skills. *Journal of Management Education, 27*, 188–204.
15. Kerry, J., Pruneau, D., Blain, S., et al. (2012). Human competences that facilitate adaptation to climate change: A research in progress. *International Journal of Climate Change Strategies and Management, 4*, 246–259.
16. Lockwood, T. (2010). *Design thinking*. New York: Alworth Communications.
17. Meadows, D., & Randers, J. (2004). *Limits to growth: The 30-year update*. White River Junction: Chelsea Green.
18. Mochizuki, Y., & Fadeeva, Z. (2010). Competences for sustainable development and sustainability. *International Journal of Sustainability in Higher Education, 11*(4), 391–403.
19. Montuori, A. (2012). Creative inquiry: Confronting the challenges of scholarship in the 21st century. *Futures, 44*, 64–70.
20. Norberg, J., & Cumming, G. S. (2008). *Complexity theory for a sustainable future*. New York: Columbia University Press.
21. Organisation for Economic Cooperation and Development (OCDE). *Building the right skills and turning them into better jobs and better lives*. http://skills.oecd.org. Visited 21-Oct-2013.
22. Parkin, S., Johnston, A., Buckland, H., & White, E. *Learning and skills for sustainable development: Developing a sustainability literate society*. Guidance for Higher Education Institutions. Higher Education Partnership for Sustainability and Forum for the Future. http://www.forumforthefuture.org.org.uk. Visited 8-Jul-2005.
23. Porter, T., & Cordoba, J. (2009). Three views of systems theories and their implications for sustainability education. *Journal of Management Education, 33*, 323–347.
24. Pruneau, D., Kerry, J., & Langis, J. (2013). Étude des compétences propices au soin et à la transformation de l'environnement. *Vertigo, 13*.
25. Pruneau, D., Kerry, M., Langis, J., & Léger, M. L. (2013). *De nouvelles compétences ΰ développer chez les élèves du primaire en sciences et technologies: pratiques et possibilités. Rapport de synthèse de connaissances*. Moncton: Université de Moncton, Groupe de recherche Littoral et vie.
26. Rieckman, M. (2012). Future-oriented higher education: Which key competencies should be fostered through university teaching and learning? *Futures, 44*, 127–135.
27. Rockstrom, J., et al. (2009). A safe operating space for humanity. *Nature, 461*, 472–475.
28. Sterling, S. (1996). Education in change. In J. Huckle & S. Sterling (Eds.), *Education for sustainability* (pp. 18–39). London: Earthscan.
29. Sterling, S., & Maiteny, P. (2005). *Linking thinking*. Perthshire: World Wildlife Fund.

30. Sterling, S., & Thomas, I. (2006). Education for sustainability : The role of capabilities in guiding university curricula. *International Journal of Innovation and Sustainable Development, 1*(4), 349–358.
31. Sternberg, R. J., Jarvin, L., & Grigorenko, E. L. (2009). *Teaching for wisdom, intelligence, creativity, and success*. Thousand Oaks: Corwin.
32. Utzschneider, A., & Pruneau, D. (2011). La prise de décision en environnement: théorie et perspectives pédagogiques. *The Canadian Journal of Environmental Education, 16*, 142–154.
33. Wals, A. (2010). Mirroring, Gestaltswitching, and transformative social learning: Stepping stones for developing sustainability competence. *International Journal of Sustainability in Higher Education, 11*, 380–390.
34. Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science, 6*(2), 203–218.
35. Withycombe, L., & Wiek, A. (2010). *Anticipatory competence as a key competence in sustainability* (Working Paper). School of Sustainability, Arizona State University.
36. World Commission on Environment and Development. (1987). *Our common future*. New York: Oxford University Press.

Chapter 15
CREAT-IT: Implementing Creative Strategies into Science Teaching

Anna Craft, Oded Ben Horin, Menelaos Sotiriou, Petros Stergiopoulos, Sofoklis Sotiriou, Sarah Hennessy, Kerry Chappell, Charlotte Slade, Margo Greenwood, Alison Black, Erić Lale Dobrivoje, Đurđa Timotijević, Aleksandra Drecun, Ana Brajović, Cinzia Belmontecinzia, and Giovanna Conforto

15.1 Introduction to CREAT-IT

For teachers, creativity and innovation is a high-risk activity and the incentives are few [28]. In a system where the centre has been the innovator, practitioners' compliance understandably becomes the habit. The dynamic of change in education in Europe has been described in terms of a set of shifts, first, from "uninformed

A. Craft (✉) • S. Hennessy • K. Chappell • C. Slade • M. Greenwood • A. Black
University of Exeter, Exeter, UK
e-mail: a.r.craft@exeter.ac.uk; s.j.e.hennessy@exeter.ac.uk; K.A.Chappell@exeter.ac.uk; C.Slade2@exeter.ac.uk; M.Greenwood@exeter.ac.uk; A.E.Black@exeter.ac.uk

O.B. Horin
Stord Haugesund University College (HSH), Stord, Norway
e-mail: oded.ben@hsh.no

M. Sotiriou
Science View, Pallini, Greece
e-mail: sotiriou@scienceview.gr

P. Stergiopoulos
Ellinogermaniki Agogi (EA), Pallini, Greece
e-mail: plagiavlitis@yahoo.gr

S. Sotiriou
Ellinogermaniki Agogi, R&D, Pallini, Athens, Greece
e-mail: sotiriou@ea.gr

E.L. Dobrivoje • Đ. Timotijević • A. Drecun • A. Brajović
Center for the Promotion of Science (CPN), Beograd, Serbia
e-mail: dleric@cpn.rs; djurdj@gmail.com; adrecun@cpn.rs; abrajovic@cpn.rs

C. Belmontecinzia • G. Conforto
FormaScienza (FS), Rome, Italy
e-mail: belmonte@formascienza.org; giovanna.conforto@formascienza.org

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_15

prescription" (in the 1980s); to "informed prescription"; then towards practitioner-led change [1]. This last was seen as the key to self-sustaining, rapid improvement. It is within this context, that the CREAT-IT project is taking forward the agenda of practitioner-led change at a European level by putting forth the case for creativity in science education. At the level of individual teachers, this implies three things happening:

- Individual teachers need to become aware of specific weaknesses in their own practice. In most cases, this not only involves building an awareness of what they do, but the mindset underlying it.
- Individual teachers need to be motivated to make necessary improvements. In general, this requires a deep change in motivation which cannot be achieved by improving material incentives alone. Such changes come about when teachers have high expectations, a shared sense of purpose, and above all, a collective belief in their common ability to make a difference to the education of the children they serve.
- Individual teachers need to gain understanding of specific best practices. In general, this can only be achieved through training and demonstration of such practices in authentic settings.

Openness of the school environment and the enhancement of teacher skills, strengthening their ability to motivate innovation and creativity is crucial. Creativity with a capital "C", the kind which changes the way we see or understand the world, never occurs on its own, but rather as part of an encouraging system. *It is precisely the enrichment of the creative elements in Science Education as an integral part of such a system, based on a wealth of existing European knowledge, which is the cornerstone of the CREAT-IT project.* The project focuses on late primary and early secondary teachers' – *in-service* – training by implementing teaching practices in which the integration of science education and other creative disciplines in formal education systems construct the *CREAT-IT Pedagogical framework*.

The CREAT-IT project aims to develop and support teacher skills in *science education* by *integrating creative, cultural disciplines and social media tools* in *science courses*, engaging students to participate in collaborative, project and case study based activities. In these activities teachers and students will be involved in collaborative and dialogue activities (Science Cafes), cultural, artistic and role-playing activities (creating original science theaters and science operas) which are connected with their science curriculum.

The main project objectives include:

1. *To propose a methodology for the effective introduction of creativity and innovation in schools*, and to take forward the agenda of practitioner-led change at a European level. The proposed work describes what may be its key contribution to the evolution of school innovation and improvement: a new approach to stimulating, incubating, and accelerating creativity and innovation which is strongly driven by users' needs. At this level the proposed project will do three things: it will capture, briefly, what we know so far about the process of encouraging schools to become more creative; it will describe the *CREAT-IT pedagogical*

framework based upon these understandings; and it will describe the practical programme of work which utilizes this model.

The CREAT-IT pedagogical framework builds on the essential features of creative learning including exploration, a dynamic of discovery, student-led activity, engagement in scientifically oriented questions, priority to evidence in responding to questions, formulations of evidence-based explanations, connection of explanations to scientific knowledge and communication and justification of explanations. These elements support creativity as a generic element in the processual and communicative aspects of the pedagogy by integrating culture, arts and science, and proposing innovative teaching strategies that will offer students high participation and enable them to generate highly imaginative possibilities. Also, the CREAT-IT approach will include three case studies in order to put forth the case of creativity in science education: science cafes, science theaters and science operas as well as the incorporation of social media tools (YOUTUBE, Glogster for online, interactive posters, blogs and photos' sharing web services) that can be utilized for educational purposes, so as to bring the worlds of science, culture and technology closer under an umbrella of collaborative activities.

2. *To design and develop training material and users' communities for teacher training, so as to utilize the outcomes of the proposed methodology afterwards in their classrooms*. Training material for *late primary and early secondary school teachers* will be utilized during the trainings, including manuals, guidelines, learning scenarios, three cases of creative science education activities, open educational resources and social media tools delivered via the CREAT-IT users' community. The users' community will be an open, web learning network that will have the following outcomes: community building and support, and the encouragement of cooperation between teachers, students and researchers.
3. *To implement a wide-spread training approach for teachers, facilitating intake of creative Science Education practices in schools*. In-service teachers will have the chance to participate in numerous training workshops, mobility activities and receive training in the CREAT-IT methodology of employing Creative Science Agents through the CREAT-IT web platform. Afterwards, teachers will elaborate demonstration activities in schools by utilizing the CREAT-IT pedagogical methodology tools, such as Science cafes, Science theaters and Write a Science Opera (WASO), providing them with resources and tools that will engage them to create their own projects collaboratively with students from all participating countries, and take part in large-scale activities. In addition to activities in the six countries involved, additional activities will take place as a result of educators and scientists from additional countries who will attend the CREAT-IT summer and winter schools.
4. *To provide guidelines towards the continued communication and exploitation of results by the education community*. A roadmap with specific guidelines for communication, sustainability and further exploitation of the project's outcomes will be established during the project's life cycle.
5. *To systematically evaluate the CREAT-IT approach*. Systematic evaluation (pre and post evaluation activities) of the proposed creative approaches and activities

will be implemented to identify project impact in terms of effectiveness and efficiency.

15.2 The Pedagogical Framework

From a policy perspective the early twenty-first century has seen a twin pillared approach from the European Commission toward fostering creativity in science education. One emphasises the need for all countries to develop innovative scientists in a global knowledge economy [30–31] and therefore the need to teach for creativity in science. The other proposes scientific literacy as an aspect of democratic citizenship, alongside the need for creative and innovative scientists [21–23] and identifying basic competence in science as contributing to individuals' personal fulfillment and development, active citizenship, social inclusion and employment. Both pillars have increasingly involved policy makers in Europe (and other parts of the world) in examining how the arts in particular can manifest with the sciences. For example, the European Ambassadors' Manifesto of the European Year on Innovation and Creativity (held throughout 2009) underlined the need to integrate science education, creativity, culture and the arts. Schools are increasingly seen as having a vital role to play in developing creativity in science education [24]. The CREAT-IT team conducted a small scale survey in early 2014 of teachers, scientists, curriculum developers and members of the CREAT-IT consortium, which revealed teachers and schools struggling to engage or needing support to access good practice available to them. The CREAT-IT project will develop creative science education through integration with the arts, by proposing a pedagogical framework which brings together a particular view of creativity, with examples of three particular approaches to integrating the arts and creativity. Drawing on a recently completed FP7 study, *Creative Little Scientists*,[1] CREAT-IT proposes the following working definition for creativity in science education: Generating *ideas and strategies* as an individual or community, *reasoning critically between these* and *producing plausible explanations and strategies consistent with the available evidence.* Such scientific creativity as fuelled by 'little c' creativity, i.e. *purposive and imaginative activity generating outcomes that are original and valuable in relation to the learner*. The vast majority (86.9 %) of respondents to the CREAT-IT survey accepted this definition and its foundation on 'little c' creativity.

CREAT-IT builds on the existing state of the art in science education, integrating the element of creativity in learning and housing the project within the framework of Wise Humanising Creativity, dialogue and difference, a process of Living Dialogic Space, and the four P's, developed mainly by Craft and Chappell at Exeter

[1]The project CREATIVE LITTLE SCIENTISTS received funding from the European Union Seventh Framework Programme (FP7/2007–2013) for research, technological development and demonstration under grant agreement no. 289081. Website: http://www.creative-little-scientists.eu/

University. In summary, Wise Humanising Creativity [5–7] argues that creators need to think about the ethical consequences of their creations as well as acknowledge their own embodied identity development as part of the creative process [4, 7] and draws on earlier work in the arts [3]. In developing or making any new idea, creators are intrinsically developing themselves and their collaborators as part of that process, and this ethical dimension is vital to responsible creativity in a world characterised by radical uncertainty [12, 14]. The accompanying notion of 'trusteeship' is vital [9]. CREAT-IT seeks to nurture such wise humanising creativity through journeys of becoming [7], which means that as creators they are also being made and 'becoming' themselves. These are developed through new forms of creative partnership between the sciences and the arts. Integrated with this is the participatory approach of creating and working in living dialogic spaces [5, 7]. These involve participants (teachers, students, researchers) in creative learning conversations – which have flatter hierarchies than more traditional student-teacher relationships – in order to foster engagement. The team's theoretical work also recognises that digital environments are inherently creative [6, 8, 9, 14, 15] and can involve possibility thinking – the transition from what is to what might be (a line of work 15 years long including [10, 11, 17, 20]); and the 4 P's: pluralities, playfulness, participation and possibilities [13]. The team also acknowledges critical discourses regarding digital environments which may deny more embodied ways of engaging, may lack domain knowledge and focus too strongly on communication per se, competitiveness in digital environments may stifle creativity; and there may be questionable ethical practices in unmonitored areas. The team acknowledges the balance to be negotiated between digital and real-world interaction.

The CREAT-IT survey revealed respondents saw a creative science teacher as constantly developing alongside their pupils, resonating with the notion of collective journeys of becoming, and being able to contribute to quiet revolutions in terms of the way things are done. Quiet revolutions [16] are incremental and cumulative ways of communities building change together over time. In this case, potentially contributing to changes in how science is taught. There were many resonances with the theoretical frame of the project, one particularly important one being that the survey showed that seeking experience, often in the arts was another characteristic of a curious creative science teacher. From this theoretical space and building on the survey findings, CREAT-IT proposes the following pedagogical framework, to be used to further develop at least three ways of fostering creative science education. Figure 15.1 offers a visualisation of the framework, informed by arts education philosophies and methods, which foster journeys of becoming and quiet revolutions.

The project has devised 12 CREAT-IT pedagogic principles currently in no particular order, each of which will be in continual conversation with the theories and ideas articulated above:

1. *Professional wisdom*: deeply contextualized knowledge often informed by intuition

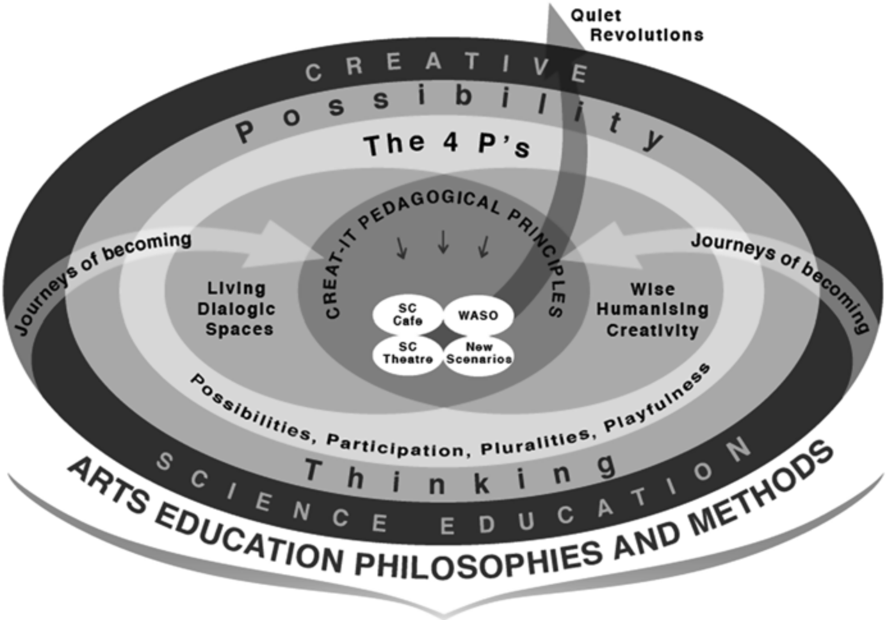


Fig. 15.1 Integration of the 12 CREAT-IT principles with the theoretical framework

2. *Individual, collaborative and communal activities for change* – all three ways of engaging.
3. *Risk, immersion and play*: creating literal space as well as 'thinking' space for these to occur.
4. *Different ways of knowing*: knowing that (propositional), knowing how (practical), knowing this (aesthetic or felt), acknowledging embodied alongside verbal.
5. *Dialogue*: between people, disciplines, creativity and identity, and ideas – acknowledging embodiment and allowing for irreconcilable difference.
6. *Relationship between 'bottom up' and 'top down'*: ideas, knowledge and practices that emerge from 'bottom up' adult-learner activity 'have a conversation' with existing recognized scientific and arts ideas, knowledge and practices that are brought into adult-learner activity most often by the adult as teacher.
7. *Interrelationship of different ways of thinking around a shared 'thread' or 'throughline'*: multiple ways of thinking (e.g. problem-finding/solving, exploring, reasoning, reflecting, questioning, experimenting) focused around shared arts/science threads or throughlines.
8. *Discipline knowledge*: allowing space for the rigorous discipline knowledge of both sciences and the arts, as well as understanding how creativity might interact with these disciplinary knowledge bases differently, albeit in the context of science education.

9. *Possibilities*: allow for multiple possibilities both in terms of thinking and spaces, and know when it is appropriate to narrow or broaden these.
10. *Ethics and trusteeship*: consider ethics of creative science processes and products, guided in decision-making by what matters to the community, and act as 'trustees' of its outcomes.
11. *Importance of materials*: materials adult professionals and learners are working with (e.g. their bodies, props, sculpting materials, Bunsen burner, test tubes, chemicals, equations) contribute to the way ideas are thought through, form and content highly intertwined.
12. *Empowerment and agency*: allow learners and adult professionals to gain a greater sense of their own agency and self-expression, to be more creative scientists and science teachers.

CREAT-IT will integrate this framework through three established and successful activities:

WASO (Write a Science Opera) – a creative professional development approach to inquiry-based art and science education in which pupils of different ages (usually ages 10–17), supported by teachers, opera artists and scientists create an educational performance. WASO focuses on science discovery in a creative framework. In addition, science communication is also a major factor, realised by allowing a scientific theme to inspire a multi-disciplinary artistic project. WASO is an application of the widespread Write an Opera method, developed at the Metropolitan Opera in New York and then imported and developed by the Royal Opera House in England [27]. It has been successfully implemented in many countries since the 1980s. WASO integrates science education into the original method by involving scientists, science higher education students, science teachers, science museums or local industry, leading an inquiry-based creative process demonstrating common impulses shared by the sciences and arts [25].

Science and Theatre (S&T) – developed by FormaScienza as a project of the Italian Ministry of Education, University and Research based on an inquiry and interdisciplinary approach, and has been implemented in 10 classes in various Italian social and geographic contexts in 2012–2013. With two experienced facilitators, a scientist and a drama teacher working in collaboration, FormaScienza considers that scientists to be creative when they *make* science by posing questions and looking for answers by hypothesis, experiment and interpretation. An inquiry-based training is used to support student's working as scientists. This includes questions the students answer by means of their own hypothesis, the designing of their own experiments and interpretation of their data. Through dialogue, students detect mistakes in the experimental procedure that classmates are using to confirm their own opposite hypothesis. The conflict among hypotheses motivates students to find theoretical and practical tools, such as statistical ones, in order to eliminate the wrong ones and avoid errors. The hypothesis confirmed by the group becomes a thesis. Students use the conflict in the experienced scientific process as a starting point for an original drama plot, by using metaphor elaborated through drama in which there is a starting-point, a conflict and a solution.

Junior Science Cafè – Science Cafés enhance motivation of students to study science by stimulating their participation in scientific debate on the premise that science is not presented as true knowledge once and for all, but as a set of alternatives that may be in conflict. The Science Café concept first appeared in France and the UK in the 1990's and has spread globally, adapting to different cultures and audiences, with three shared values:

- It occurs in an informal meeting place creating a welcoming and comfortable atmosphere,
- It is open to everyone, and especially those who do not usually engage in science discussions
- It is run on the principles of free speech, listening to and respecting opinions of others. Everyone in the audience who has something to say can contribute to the debate.

The Junior Science Café, for students aged 11–18, led since 2008 by FormaScienza, has collaborates with scientific institutions and individual scientists in Rome. In the common Junior Science Café practice, students are the audience of a science café. Following the Junior Science café practice, the students are organisers of the science café and the audience includes members of the general public (typically parents or other tudents). In this practice the students choose the theme and related questions, search on the internet and invite researchers who are experts about the chosen theme to ask them questions and organise a public event.. This allows the students to develop the ability to search and select scientific information, particularly necessary given the role mass-media play in representing science. Digital social networking is used [2, 29].

15.3 Implementing the Pedagogical Framework

15.3.1 The Implementation Characteristics

As the educational systems across Europe move towards the strategic agenda of Europe 2020, teachers need to adapt in diverse environments – not necessarily inside a school – where new technologies and information in a global sense are becoming part of everyday life. The challenge for Science teaching in school environments can only be affected by life itself, only in our days perceptions of life are more complex than ever.

Implementation strategy is characterized by two basic aspects:

(a) *To visualize the differences*. Students' thorough comprehension of the difference between everyday digital-school environments and the real life world is achieved by building a vital way of interaction between them and the embracement of knowledge as an answer to a question. In this way Inquiry Based Science Education is conceived not only as a creative tracking between artifacts of knowledge but as an active way of balancing between information, perception and a targeted achievement.

(b) *"To act is to learn and to learn is to act"*. Within the known issues of contrasts between national policies – even ethics – but also taking in account substantial differentiations in the school features themselves, the tempting task of building an implementation perspective for the Creat-IT project is compensated by encouraging teachers in using the fundamental tools of human interaction. In the digital world, European school environments not only adopt their features catching up society but they will face the challenge to expand their effect focusing in the creativity of the action itself. Implementing the 'Learning by doing' Aristotelian version "ἃ γὰρδεῖ μαθόντας ποιεῖν, ταῦτα ποιοῦντες μανθάνομεν" ("For the things we have to learn before we can do them, we learn by doing them", Nicomachean Ethics), Creat-IT project seeks to adapt its pedagogical framework in teachers' needs by overcoming boundaries of school features or even equipment where possible.

Attempting to provide teachers with innovative approaches in Creative Science teaching, the pedagogical framework is implemented across the countries of the consortium. A significant number of workshops is coordinated giving teachers the opportunity to reflect the 12 CREAT-IT pedagogical principles in the three case studies the project proposes.

15.3.2 The Phases of Implementation

Apart from providing teacher-training, the series of workshops introduced during the CREAT-IT project aim to create a transnational sense of exchanging of ideas and practices gained through the workshop procedure. Towards the realization of this goal, a large-scale educational social media project supports the CREAT-IT web-platform. Communities of teachers throughout the countries of the consortium are able to exchange not only scenarios based on the project case studies, but also ideas and practices which help them collaborate in a dynamic cross-curricular environment providing timeline features, storage and interconnected use of digital educational objects.

The core implementation scheme can be described by two cycles of workshops (Phases A and B) and a third stage of cross-country teacher-community collaboration (Phase C) leading to a European contest based on the CREAT-IT educational scheme (Fig. 15.2).

Phase A represents the series of workshops introducing the principles of the CREAT-IT pedagogical framework and the three case studies of the project. At a second stage, teachers are actively engaged in developing educational scenarios using the project's portal.

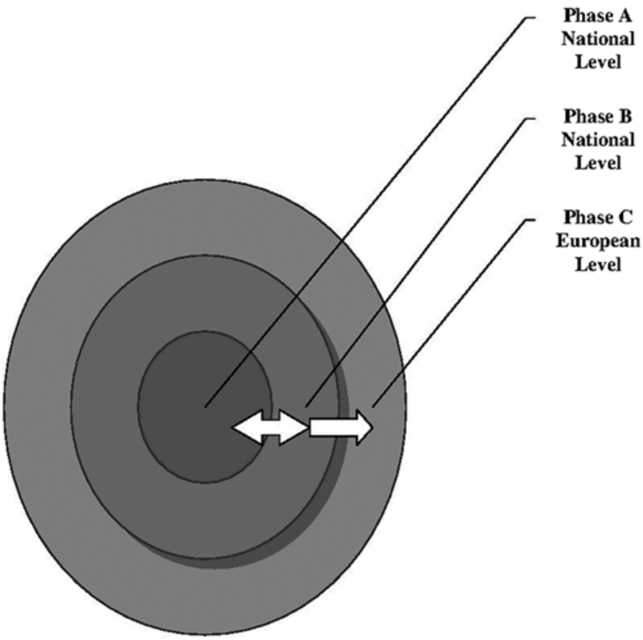


Fig. 15.2 Creat-IT implementation phases

Phase B represents the series of workshops following. During these workshops, adaptations based on the previous feedback are implemented. Demonstration activities involving students may support the outcomes of this phase.

Phase C represents the mature stage of the project's implementation plan. The project's teacher communities exchange plans of making a pan European contest of best practices derived from the project's outcomes up to this point.

15.3.3 A New Way to Conceive Science and the Arts

"Creativity is a fundamental dimension of human activity. It thrives where there is dialogue between cultures, in a free, open and diverse environment with social and gender equality. It requires respect and legal protection for the outcomes of creative and intellectual work. Creativity is at the heart of culture, design and innovation, but everyone has the right to utilise their creative talent. More than ever, Europe's future depends on the imagination and creativity of its people" (European Ambassadors for Creativity and Innovation, 2009). Art is nothing more than fundamental human need for exploration and communication. Science can only follow these fundamental aspects of well being by fostering creativity as part of a global neglected language that inspires progress. The three case studies represent the fundamental aspects of human creative activities. WASO and Science Theatre require the human live performance of an event which takes place in front of an audience while Science Café fosters the social aspect of engagement through conversation and the exchange of ideas.

> Collaboration within Europe in science, technology, education, design and culture needs to be further opened up to the rest of the world. (European Ambassadors for Creativity and Innovation, 2009).

15.3.4 The Training Materials

Training materials are being developed by the project to support and deepen the project's impact and presence in Europe's schools. These materials, which will be made available in English, Serbian, French, Italian Greek and Norwegian, include the following sections: General Guidelines for Creative Approaches to Science Teaching; Specific Guidelines for each Case Study (Junior Science Café, Write a Science Opera (WASO) and Science Theater); Implementation scenarios for the mentioned three case studies; Specific samples of how to implement these three case studies in classrooms (available for all three case studies).

15.3.5 Users' Communities Environment

The users' communities environment will provide tools for community building and support, and will encourage cooperation between teachers as well as students. Starting its operation as of June 2014, it will be a comprehensive open learning network where teachers can access their colleagues' course materials, share their own and collaborate on affecting their everyday practice.

All consortium members will provide content, so as to establish an open web space for teachers which will be functional not only from a technical perspective but also from a pedagogical one. The platform will use Web 2.0 features (tags, ratings, comments, reviews, and social networking) to create an online experience that engages teachers in sharing their best creative science teaching practices. Trainees will have the opportunity to upload their own teaching material and share it with community members.

Furthermore, a shared workspace area for efficient online collaboration will be used. The usage of the platform's group management functions will enable the consortium to track the learners' actions and display social interactivity. The platform can also be operated in tandem with the website's statistics in order to extract information about evaluation activities and monitor the geographical impact of local, national or European dissemination activities.

15.4 Evaluation, Quality Assurance within the Pedagogical Framework

Evaluation is a generic process defined at its most general level as "the systematic determination of merit, worth, and significance of something or someone and define the making of evaluation as an informed act of ascertaining or fixing the value or worth of a given project or product" [32]. The meaning of the evaluation differs from one situation to another, and from one project to another. The nature of learning and teaching projects varies considerably which means that no one evaluation methodology or one suite of techniques will 'fit' all projects. It is necessary to match the evaluation approach with the particular project. Moreover, different objectives are set at different stages in a project and so the focus for evaluation will change. It is therefore important to involve the evaluator throughout the whole lifetime of the project.

The CREAT-IT project aims to develop and support teacher skills in *science education* by *integrating creative, cultural and artistic disciplines and social media tools* in *science courses*, engaging students to participate in collaborative, arts-informed activities.

The main aim of the evaluation of the CREAT-IT project is to observe, systematically collect and analyse data regarding CREAT-IT pedagogical framework and the proposed training materials and training and implementation activities, in order to reinforce efficiency and effectiveness of the project activities in fostering creativity within science education and, therefore, ensure sustainability of the project's outcomes.

Evaluation of the CREAT-IT project ensures systematic evaluation and QA of the proposed framework and the proposed training materials, as well as training and demonstration activities, in order to identify their impact in terms of effectiveness and efficiency. All data gathered as a result of the evaluation and quality assurance procedures will serve for the production of the Evaluation Report at the end of the Project.

Theoretical Evaluation and QA Framework: Concerning existing evaluation theory and practice, a constructivist evaluation approach is proposed. Its foundation in constructivism is based in assumption that humans gain knowledge and meaning from interaction and experience. Thus, evaluation emphasizes first-hand experience with a program, involving all stakeholders (project partners, teachers, students etc.) to assist in conducting the evaluation. This type of evaluation is able to show the complexities of a program when participants are involved by reflecting their everyday reality and by including all of the relevant voices.

Concerning the project design and its objectives, a formative evaluation approach is proposed. Formative evaluation implies that evaluation activities will be conducted continuously, through the whole lifecycle of the project, providing feedback on project achievements and suggesting improvements whenever problems are identified, therefore should serve as a process of learning from the project. It also implies collecting information on project achievements and critical aspects and encouraging communication among all the actors involved.

Evaluation objectives: More specific evaluation objectives are to explore and determine:

- Trainees' perception of the proposed training materials and CREAT-IT's pedagogical framework.
- Trainees' perception of the training activities (perceived comprehensiveness, utility and applicability of gained knowledge and skills in their everyday work).
- Trainees' expectations of the implementation of CREAT-IT's methodology in their teaching practice in terms of perception of their own ability to implement the proposed activities.
- Trainees' needs assessment regarding the future implementation of the proposed activities (in terms of the required skills and knowledge, institutional support, financial resources, equipment etc.)
- Experiences of teachers who participated in demonstration activities and their assessment of process of implementation and its effects.

More specific QA objectives are:

- To follow-up project achievements and critical aspects
- To encourage other WP leaders to instantly report problems, stress quality assurance issues and suggest corrective actions
- To propose suitable corrective actions in cases of non-conformities

Methodology and Instruments: Respecting the project design and its objectives both quantitative and qualitative methods will be used.

15.5 CREAT-IT Sustainability and Vision

The institutions participating in CREAT-IT have already established collaborations with a great number of educational and research organizations via previous and/or ongoing projects (e.g. Creative Little Scientists, Discover the COSMOS, Open Discovery Space [18]) and have established elaborate networking activity amongst science teachers and curriculum developers. This ensures that CREAT-IT activities will go beyond the project's activities and, more importantly, beyond the CREAT-IT network of teachers and students.

The CREAT-IT Communities Support Environment will offer (portal.creatit-project.eu, it will be operational from June 2014) free membership for teachers, students and other stakeholders, including access to rich open educational resources and scenarios in all partner languages (both pre-existing and developed during the project). Members will be invited to share creative *Science Education* materials (i.e. demos of Science Operas, Science theatres and presentations of science cafes) created in all relevant educational settings (videos, online posters, essays, music syntheses, laboratory stories, etc.) by uploading these on the web platform. The CREAT-IT web platform will act as the HUB with a pool of educational resources, training and information material and tools for teachers (science courses in physics, maths, biology as well as other scientific fields). Utilizing this content, users will be able to design their own Creative Science teaching activities based on the CREAT-IT pedagogical framework. The evaluation of the CREAT-IT approach by participants in the implementation activities, key stakeholders and the participating institutions will, therefore, result, in the provision of sustainable teaching tools, especially for science courses in late primary and early secondary education.

Another main point that will ensure sustainability of the project is the mobility and in-service training activities (training courses, seminars, educational conferences) aimed at engaging more teachers in primary or/and secondary science education. Mobility activities among schools will also establish e-Twinning collaborations. New teachers will take part in courses and training seminars provided in the Universities that are main partners of this project (e.g. the Write A Science Opera (WASO) method training course, at Stord, Norway during the 1st week of August, 2014). HSH and EXETER will integrate the methodological approach of CREAT-IT and its tools in undergraduate and postgraduate teacher training courses and will also create collaborations with other universities to expanding CREAT-IT usability in other Higher Education Institutes.

Furthermore, partners are in the process of enlarging the amount of countries in which experienced practitioners of Write a Science Opera (WASO) are based, with the help of the RESEO network, enabling cooperation among schools and operas on EU level. Such a widening will be based on the knowledge gained during the current project. There is also growing interest in the United states for the WASO method, where HSH representatives presented WASO in the summer of 2013, and the proposed project will thus support the partners' potentials to collaborate with recipients of NSF grants in the field of creative science education in the USA, one example of which is the work of visiting scholar to HSH (Norway) Dr. Walter Gershon (Kent State University) on musical approaches to science education, and specifically hip-hop music and use of ICT tools [26]. Many of the participating institution (e.g. FormaScienza, CPN, Science View, EA) are already organizing science cafes and science theatre performances and, following the project's completion, will include the CREAT-IT outcomes in their activities, so as to promote the project's results on National level. Furthermore the already existing SciCafeNetwork – http://scicafe.eu/ (EA, Formascienza are included) – will incorporate the proposed activities, especially in the category of junior science cafes [2].

The vision of CREAT-IT is to constitute a common set of guidelines and recommendations on how scientific work can be used to provide an engaging educational experience through the exploration of "real science" in a creative way. Research on learning science points at the fact that it involves development of a broad array of interests, attitudes, knowledge, culture and competencies. Clearly, learning "just the facts" or learning how to design simple experiments is not sufficient. In order to capture the multifaceted nature of science learning, the *CREAT-IT* approach proposes a roadmap that includes a series of "strands for the design of the Educational and Creative Activities" that articulates the science-specific capabilities. The strands will provide a framework for thinking about elements of scientific knowledge, creative action and practice. The proposed framework will also describe a series of support functions that have to be deployed in order to ensure safeguarding of the long-term impact of the proposed activities. Such support actions could include the integration and coordination of educational and creative activities between groups across different research institutions; supporting the science community and scientists interested in educational and creative activities; supporting the education communities interested in scientific content and creative applications; supporting special events and activities and providing means and tools for web-based communication and collaboration. The proposed framework will provide a useful reference for helping educators and creative groups (artists, musicians, as well as educational departments of opera companies, theaters, etc.) in the informal science education community to articulate learning outcomes as they develop programs, activities, and events to further explore and exploit the unique benefits of introducing *creativity* in schools.

References

1. Barber, M. (2002). *The next stage for large scale reform in England: From good to great*. Background paper for the Federal Reserve Bank of Boston 47th economic conference, 'Education in the 21st century: Meeting the challenges of a changing world', Cork, Ireland, 19–21 June 2002.
2. Belmonte, C., & Castellani, T. (2012). The 'CaffèScienza Junior' project: Students protagonists of their scientific training. In P. Koulouris (Ed.), *SciCafé 2012 conference and events: Europe's science cafés thinking forward. Book of proceedings*, Epinioa, Athens. http://www.scicafe.eu/sites/all/themes/newspro/docs/SciCafe2012_proceedings_long_online.pdf
3. Chappell, K. (2006). *Creativity within late primary age dance education: Unlocking expert specialist dance teachers' conceptions and approaches* (Ph.D. thesis). Available from http://kn.open.ac.uk/public/document.cfm?docid=8627. Retrieved April 2014.
4. Chappell, K. (2008). Towards humanising creativity. *UNESCO Observatory E-Journal*. Special Issue on Creativity, policy and practice discourses: productive tensions in the new millennium, *1*:3. Available from http://www.abp.unimelb.edu.au/unesco/ejournal/vol-one-issue-three.html. Retrieved Dec 2008.
5. Chappell, K., & Craft, A. (2011). Creative learning conversations: producing living dialogic spaces. *Educational Research, 53*(3), 363–385.
6. Chappell, K., Rolfe, L., Craft, A., & Jobbins, V. (Eds.). (2011). *Close encounters: Dance partners for creativity*. Stoke on Trent: Trentham Books.
7. Chappell, K., Craft, A., Rolfe, L., & Jobbins, V. (2012). Humanising creativity: Valuing our journeys of becoming. *International Journal of Education and the Arts. 13*(8), 1–35. http://www.ijea.org/v13n8/. Retrieved Jan 2013.
8. Chappell, K., Walsh, C., & Craft, A. (2013). *C2Learn learning design for CER: Deliverable No* D2.2.1. http://www.c2learn.eu/?q=node/116. April 2014.
9. Claxton, G., Craft, A., & Gardner, H. (2008). Concluding thoughts: Good thinking – Education for Wise Creativity. In A. Craft, H. Gardner, & G. Claxton (Eds.), *Creativity, wisdom and trusteeship: Exploring the role of education*. Thousand Oaks: Corwin Press.

10. Craft, A. (1999). Creative development in the early years: Some implications of policy for practice. *Curriculum Journal, 10*(1), 135–150.
11. Craft, A. (2002). *Creativity and early years education*. London: Continuum.
12. Craft, A. (2008) Trusteeship, wisdom and the creative future of education? *UNESCO observatory, E-Journal*, *1*, 3, Special Issue: Creativity, policy and practice discourses: Productive tensions in the new millennium.
13. Craft, A. (2011). *Creativity and educational futures*. Stoke on Trent: Trentham Books.
14. Craft, A. (2012). Childhood in a digital age: Creative challenges for educational futures. *London Review of Education, 10*(2), 173–190.
15. Craft, A. (2013). Childhood, possibility thinking and wise, humanising educational futures. *International Journal of Educational Research, 61*, 126–134.
16. Craft, A. Chappell, K., Rolfe, L., & Jobbins, V. (2012). Reflective creative partnerships as 'meddling in the middle': Developing practice, *Reflective Practice*, DOI:10.1080/14623943.2012.670624, http://dx.doi.org/10.1080/14623943.2012.670624
17. Craft, A., Cremin, T., Burnard, P., Dragovic, T., & Chappell, K. (2012). Possibility thinking: Culminative studies of an evidence-based concept driving creativity? *Education*, 3–13. *International Journal of Primary, Elementary and Early Years Education*, doi:10.1080/03004279.2012.656671, Link: http://dx.doi.org/10.1080/03004279.2012.656671
18. Creative Little Scientists, see Footnote 1, Discover the COSMOS: http://www.discoverthecosmos.eu, Open Discovery Space: http://www.opendiscoveryspace.eu
19. CREAT-IT is a project co-funded by the European Commission under the Comenius Programme (Contract Number: 539818-LLP-1-2013-1-NO-COMENUS-CMP). The partners of CREAT-IT are: Stord/Haugesund University College (Norway), Exeter University (UK), Elinogermaniki Agogi – Research & Development Department (Greece), Science View (Greece), Forma Scienza (Italy), CENTER FOR THE PROMOTION OF SCIENCE (Serbia), European Network for Opera and Dance Education (Belgium).
20. Cremin, T., Chappell, K., & Craft, A. (2013). Reciprocity between narrative, questioning and imagination in the early and primary years: Examining the role of narrative in possibility thinking. *Thinking Skills and Creativity, 9*, 135–151.
21. European Commission. (2004). *The teaching profession in Europe: Profile, trends and concerns. Report IV: Keeping teaching attractive for the 21st century-General lower secondary education: Key topics in education in Europe* (Vol. 3). Brussels: Audiovisual and Culture Executive Agency.
22. European Commission. (2007). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a European Agenda for Culture in a Globalizing World*. Brussels: Office for Official Publications of the European Communities.
23. European Commission. (2007). *Key competences for lifelong learning: European reference framework*. Brussels: Office for Official Publications of the European Communities.
24. European Commission. (2009). *Manifesto of the European ambassadors for European year of creativity and innovation*. Available from: http://ec.europa.eu/education/lifelonglearningpolicy/doc/year09/manifesto_en.pdf. Retrieved April 2011.
25. Garoian, C. R., & Mathews, J. D. (1996). A common impulse in art and science. *Leonardo, 29*(3), 193–196.
26. Gershon, W. S., & Ben-Horin, O. (2014). Deepening Inquiry: What processes of making music can teach us about creativity and ontology forinquiry-based science education. *International Journal of Education and the Arts (volume number unknown at time of publishing).*
27. Griffiths, H. (2012). *Write an opera teachers' notes*. London: Royal Opera House and Den Norske Opera & Ballett.
28. Hannon, V. (2009). *'Next Practice' in education: A disciplined approach to innovation*. Innovation Next Practice. Website: www.innovation-unit.co.uk

29. Junior Science Cafe Guideline: http://www.scicafe.eu/sites/all/themes/newspro/docs/JUNIOR_SCI_CAFE_How%20To.pdf
30. Official Journal of the European Union. (2006). Recommendation of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning, (2006/962/EC).
31. Scaltsas, T., Stenning, K., Alexopoulos, C., Chappell, K., Craft, A., & Walsh, C. (2013). *Co-creativity assessment methodology: C2Learn deliverable no D2.3.1.* http://www.c2learn.eu/?q=node/116. April 2014.
32. Stufflebeam, D. L., & Webster, W. J. (1980). An analysis of alternative approaches to evaluation. *Educational Evaluation and Policy Analysis, 2*(3), 5–19.

Chapter 16
The PATHWAY to Inquiry-Based Teaching – European Perspective to Shift Science Classroom Realities

Sofoklis Sotiriou, Agueda Gras-Velázque, and Franz X. Bogner

16.1 PATHWAY Vision

PATHWAY (www-pathway-project.eu) vision follows a standard-based approach to teaching science by inquiry. (1) It supports the adoption of inquiry-teaching by demonstrating ways to reduce constrains presented by teachers and school organisations, (2) it demonstrates and disseminates methods and exemplary cases of both, effective introduction of inquiry to science classrooms and professional development programmes, as well as (3) it delivers a set of guidelines for the educational community to explore and exploit the unique benefits of the approach in science teaching. In this way, PATHWAY facilitates the development of communities of practitioners of inquiry enabling teachers to successfully learn from each other (see also, [20]).

S. Sotiriou (✉)
Ellinogermaniki Agogi, R&D, Pallini, Athens, Greece
e-mail: sotiriou@ea.gr

A. Gras-Velázque
European School-Net, Rue de Trèves 61, Brussels B-1040, Belgium
e-mail: agueda.gras@eun.org

F.X. Bogner
Centre of Math & Science Education (Z-MNU), University of Bayreuth,
University Campus NW-1, Bayreuth D-95447, Germany
e-mail: franz.bogner@uni-bayreuth.de

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_16

16.2 Background and Introduction

Inquiry activities generally are the heart beats when designing Inquiry-Based Science Education (IBSE). Any learning activity, even when distinct from contents, needs to design learning fields, without neglecting historical roots of instructional design [14]. Consequently, Beetham [2] has defined a learning activity as a Learner's interaction with others and with an environment as well (optionally involving resources, tools and services) by simultaneously responding to a specific learning outcome. Within this context, Conole [7] described three dimensions to constitute a learning activity: (1) The context within which an activity occurs, which precisely includes the subject matter (i.e., physics, geography, math, arts), the level of difficulty, the intended learning outcome (i.e., recall, understanding) and the environment within which an activity takes place (i.e., computer-based, lab-based). (2) The involved pedagogical approach, for instance, problem-based learning, inquiry-based learning. (3) The tasks undertaken to achieve the intended learning outcome which is describable by the type of a task (i.e., reading, writing, viewing), the techniques used (i.e., presenting, discussing, arguing), associated tools and resources (i.e., computer, software, mobile devices), the interaction (i.e., class-based, group-based) and roles (teacher, learner, group leader) of those involved and the assessments (i.e., formative, summative) associated with the learning activity [12].

The concept of learning design is far from new. While teacher may regard themselves as 'designers', they consciously and reflectively, as well as subconsciously, engage in the process of design and make design-decisions before and in everyday lesson [2]. However, an explicit focus on learning design is in tune with an increased focus in educational theory (for instance, regarding the role of a student activity [17, 18]; this may occur even distinct from a content transmission. From a science teacher's perspective, two main advantages may exist associated with the concept of designing for any learning: firstly, it may provide a framework for deeper reflection and more creative educational practice [11]; and, secondly, it may offer a framework for participation in sharing and reusing /repurposing of practice within professional communities [21, 22].

Teaching science by inquiry is a multi-faceted, contingent practice. Out of the complex variable framework, some of the factors combine to shape the way in which teachers design lessons for IBSE: the character of the national teaching and the current syllabus; the assessment policy regime; the character of the school or institutional learning and teaching culture; the teachers' conceptions of teaching and learning; the subject-specific pedagogical traditions; the availability of educational resources; the affordances of formal and informal learning spaces; and, of available technologies. Design for IBSE involves exercising informed, professional judgments: incorporating IBSE into frameworks of wider curriculum requirements; creating or selecting activities that will motivate and further engage students; establishing appropriate learning outcomes and assessments; approaches to provision of guidance and support; using specialist equipment and digital technology; selecting learning resources including readings and links to useful websites; addressing classroom management issues and minimizing of any risks involved in hands-on activity. Any science teacher may take notes about more/less successful approaches well in order to strengthen certain inquiry aspects or to reflect on what should be kept into the inquiry process for the next year. While much of the design for learning work involved in IBSE entails planning and reflection, it also involves interacting with students and thinking fast during inquiry activity and taking in-process decisions.

The focus of learning design is the learning activity: what counts as most important in relation to learning outcomes is what the student does [3]. Activity encompasses mental elements (e.g., a meta-cognitive reflection on the process of analysing scientific data) and physical elements (e.g., using laboratory equipment or a digital scientific tool) [10, 19]. However, while the ultimate focus of any design is the learning activity, which is mediated in formal educational settings by tasks [2]. Tasks designed by teachers thus can be seen as a key stimulus and resource for student activity. Within the PATHWAY framework, teacher followed the multiple feature frame of questioning, evidencing, analysing, explaining, connecting, communicating and reflecting (adapted from [1]).

A design for learning activities not necessarily needs support by the use of digital technology, nowadays it increasingly does. Therefore, teacher need appropriate assistance to adjust existing lesson plans and update practice scenarios accessible so as to facilitate reuse/repurposing and to plan new learning activities [13, 16].

Two potential strands need distinguishing [7]:

1. The first is concerned with using technology to enable the description or representation and the making accessible, of concrete examples of best practice. Potential ways of describing and making learning designs accessible by using technology platforms and tools include: digital case studies (text-based and video-based), controlled vocabularies (metadata), digital design patterns, concept maps, temporal sequences, flow diagrams and visual interfaces [8]. 'One size does not fit all' and different approaches to representation are suited to different purposes [12].
2. The second strand – separate, but often linked in practice – is concerned with using technology to provide principled guidance for the practice of design, by means of creating digital 'pedagogic planners' or 'learning design toolkits'.

For example, one PATHWAY Best Practice was the Natural Europe initiative which primarily connected museums and school classrooms via e-learning. As natural history and education inadequacy in formal and informal contexts is becoming an increasingly challenging issue, harvesting the potential of digital libraries in natural history museums appears as a very attractive option. An impressive abundance of high quality digital contents within natural history museums around Europe often remains largely unexploited due to a number of barriers, such as: (1) the lack of interconnection and interoperability between the storage systems of museums, (2) the lack of centralized accessibility, (3) the inefficiency of current content organization and the metadata used as well as (4) the existing language barriers between countries and even regions.

16.3 Diffusion of Inquiry through Activities in the Teacher Education and the Professional Development as Well

The main contribution of the PATHWAY framework was forming standard-based foundation to teaching science by inquiry that outlines instructional models and help teachers to organise effectively everyday practice. The underlying principles governing the presented standardization approach is based on the concepts and the theoretical approaches deriving from recent educational research on the field. A deep understanding of content teaches pre-service teachers many options to motivate young minds, especially with the appropriate use of technology, and to guide them in active and extended scientific inquiry, and instils a knowledge of – and basic skills in using – effective teaching methods in the discipline.

Such a process allows all stakeholders to move in the same direction, with the assurance that the risk they take in the name of improving science education will be supported by policies. This work adds its contribution to the implementation of PATHWAY by setting out the principles that should underpin the inquiry-based science education of all students throughout their schooling. It argues that students should be helped to develop “big ideas” of science and about science that will enable them to understand the scientific aspects of the world around and make informed decisions about the applications of science.

For this understanding, students need authentic learning experiences (best practices) that are interesting and engaging and seen as relevant to their lives. The approach also considers the progression from small ideas about specific events, phenomena and objects to more abstract and widely applicable ideas and highlights the significant aspects of inquiry-based pedagogy that are required to support this progression.

Despite the evidence, and the fact that almost every other profession conducts most of its training in real-life settings (doctors and nurses in hospitals, lawyers in courtrooms, consultants with clients), just a few teachers professional development approaches take place in the teacher’s own classrooms, the place in which it would be precise and relevant enough to be the most effective.

Teachers are the key players in the renewal of science education. The effective widespread use of inquiry and problem-based science teaching techniques in primary and secondary schools heavily depends on them. Many studies showed the science education community as using the term inquiry in a variety of ways, including the general categories of inquiry as content and inquiry as instructional technique, and is unclear about the term’s meaning [5]. Relevant studies indicate positive statements of teachers about the value of inquiry, but still preferring teaching factual knowledge which is showing up on tests [6]. The main consideration is of inquiry as an instructional technique. For not teaching science by inquiry, not employing it for introducing the content or not using experiences oriented to inquiry, teachers are giving a number of reasons. Among them are problems managing the classroom, difficulty meeting curriculum requirements, troubles obtaining supplies and equipment, dangers that some experiments might pose for students, and concerns about whether inquiry really worked. The widespread espoused support of inquiry is more simulated than real in practice. The greatest set of barriers to the teacher support of inquiry seems to be its perceived difficulty. There is a legitimate confusion over the meaning of inquiry in the classroom. There is concern over discipline. There is worry about adequate preparation of children for any next level of education. There are problems associated with the teachers' allegiance to teaching facts and to following the role models of the college professors [9].

There is plenty of evidence pointing to the difficulty of empowering teachers to engage in innovation, especially in tightly accountable systems based on performance targets (e.g. [5]). In science education there is no shortage of energy and expertise, and certainly no lack of commitment or motivation amongst teachers. How could we support them and give them the creative space they need to be innovative? What sort of interventions could both release professional imagination, whilst encouraging work that is disciplined and system relevant? How can the system learn from the resultant innovation and its process characteristics so that these can be taken to scale? How can busy teachers become aware of approaches and techniques which are emerging in other sectors? It is enormously difficult in practice to be fully alert to developments and methods outside one's "zone of operation" which offer improvement potential. Some school leaders do manage to scan other horizons for ideas with transfer potential. How far can this be done on their behalf, to shortcut the investment of time, and also optimize the scope for adaptation?

For an effective implementation of inquiry in the classroom, three crucial ingredients are needed: (1) teachers must understand precisely what scientific inquiry is; (2) they must have sufficient understanding of the structure and content of science itself; and (3) they must become skilled in inquiry teaching techniques. Science teachers should know the differences between all three concepts: Inquiry is regarded a description of methods and processes that scientists use; Inquiry is a set of cognitive abilities that students might develop; Inquiry is a constellation of teaching strategies that can facilitate learning about scientific inquiry, developing the abilities of inquiry, and understanding scientific concepts and principles. At the level of individual teachers, these three concepts might support three things occurring: (1) Individual teachers need to become aware of specific weaknesses in their own practice. In most cases, this not only involves building an awareness of what they do but the mind-set underlying it. (2) Individual teachers need to be motivated to make necessary improvements. In general, this requires a deeper change in motivation that cannot be achieved through changing material incentives. Such changes come about when teachers have high expectations, a shared sense of purpose, and above all, a collective belief in their common ability to make a difference to the education of the children they serve. (3) Individual teachers need to gain understanding of specific best practices. In general, this can only be achieved through the demonstration of such practices in authentic settings. Altogether 10.053 teachers have been trained within all participating countries (Fig. 16.1).

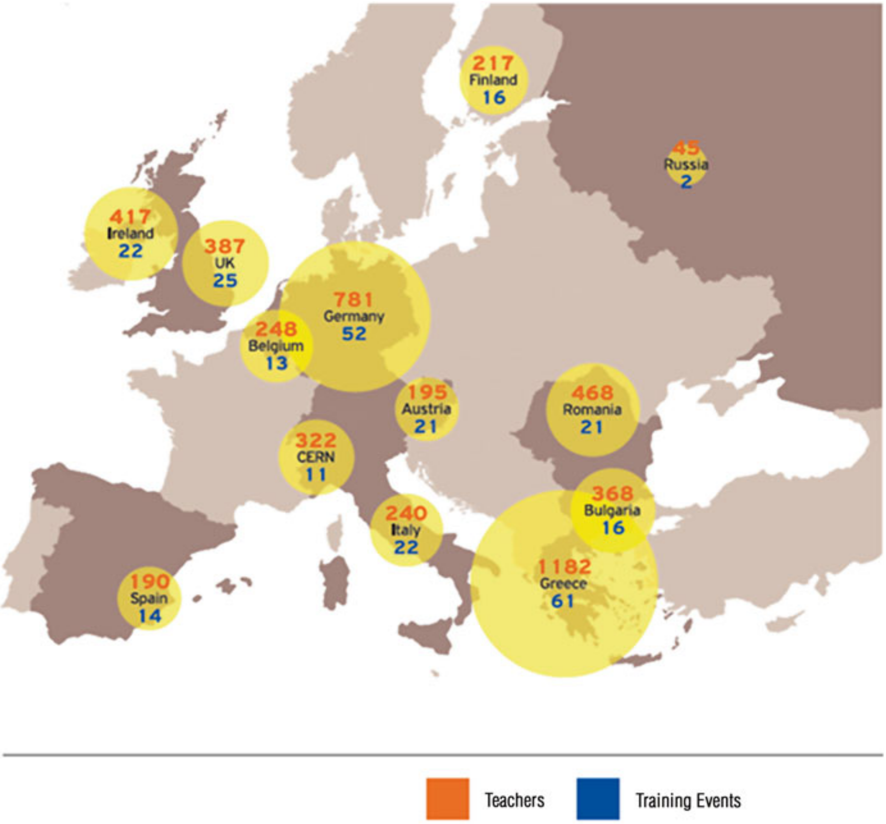


Fig. 16.1 Overview of the participating teachers and training events per country within PATHWAY initiative

16.4 Results and Discussion: Defining and Disseminating Best Practices in IBSE

PATHWAY is introducing a standard-based approach which outlines instructional models that will help teachers to organise effectively their instruction (Fig. 16.2). Such a perspective begins with the educational outcomes – set clear and high expectations for the performance of the students – and then identifies the best strategies to achieve the outcome. In PATHWAY, the process of inquiry is the very heart of what teachers need to do in their lessons. Inquiry not only tests what students know, it encourages students to provide detailed explanations as opposed to simplistic answers. It uses hands-on approaches to learning [15], in which students participate in activities, exercises and real-life situations to both learn and apply lesson content. IBSE provides a method where students not only experience what to learn but how to learn. High-quality teaching, especially in the sciences, focuses on the skills of

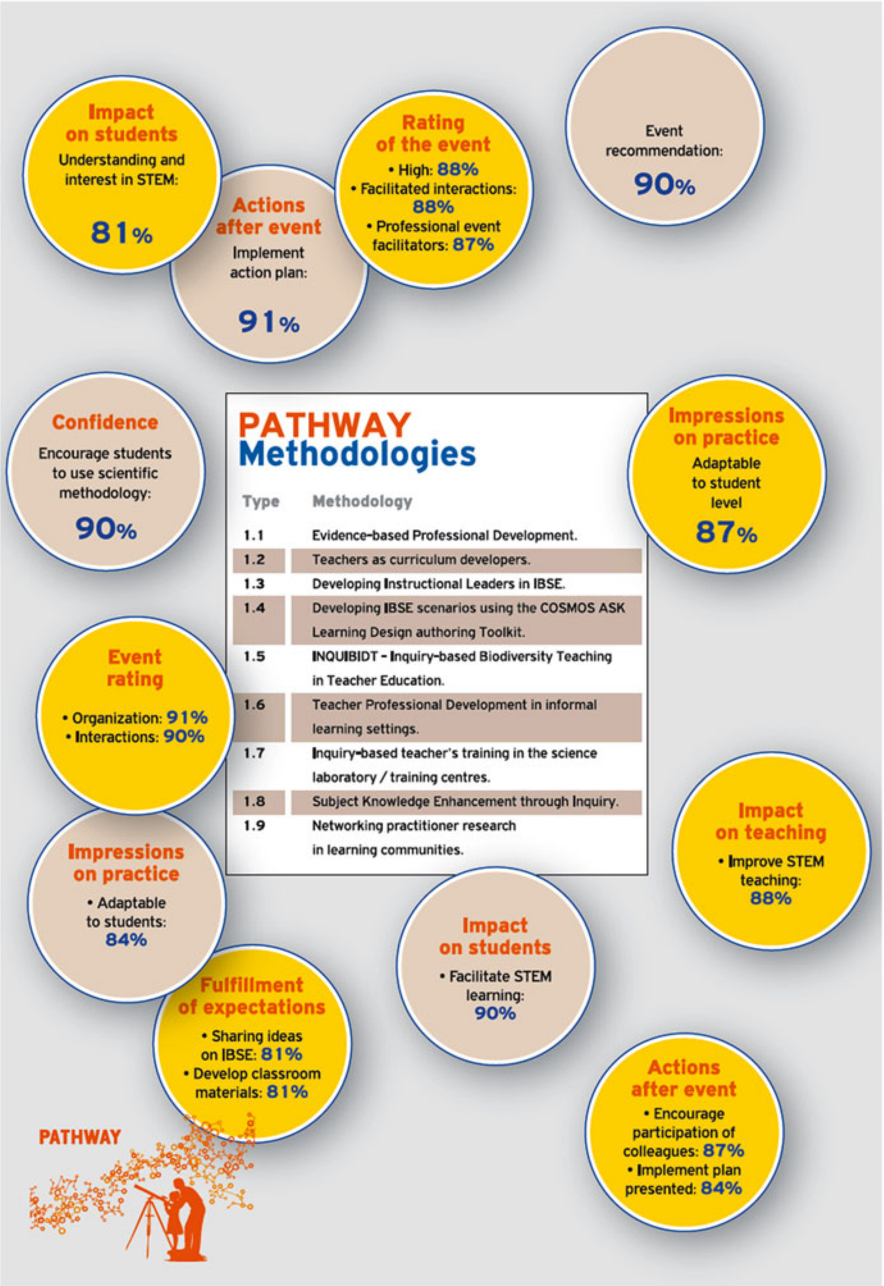


Fig. 16.2 Overview of the main PATHWAY professional development approaches and indicative results from their implementation with teachers' communities

observation, information gathering, sorting, classifying, predicting and testing. A good science or mathematics teacher encourages students to try new possibilities, to venture possible explanations and to follow them to their logical conclusions. It builds on strengths rather than trying to stamp out weaknesses.

The standard-based PATHWAY approach highlights and promotes best practices in teaching science by inquiry. Such a process will help to chart the course into the future. By building on the best of current practice, the PATHWAY approach aims to take us beyond the constraints of present structures of schooling toward a shared vision of excellence.

The PATHWAY Standard-Based approach recommends a multifaceted methodology to support science teachers effectively promoting inquiry: (1) Plan an inquiry-based science program for their students by developing both short- and long-term goals that incorporate appropriate content knowledge. (2) Implement approaches to teaching science that cause students to question and explore and to use those experiences to raise and answer questions about the natural world. The learning cycle approach is one of many effective strategies for bringing explorations and questioning into the classroom. (3) Guide and facilitate learning using inquiry by selecting teaching strategies that nurture and assess student's developing understandings and abilities. (4) Design and manage learning environments that provide students with the time, space and resources needed for learning science through inquiry. (5) Experience science as inquiry as a part of their teacher preparation program. Preparation should include learning how to develop questioning strategies, writing lesson plans that promote abilities and understanding of scientific inquiry and analysing instructional materials to determine whether they promote scientific inquiry. (6) Receive adequate administrative support for the pursuit of science as inquiry in the classroom. Support can take the form of professional development on how to teach scientific inquiry, content and the nature of science; the allocation of time to do scientific inquiry effectively; and the availability of necessary materials and equipment.

Regarding students' abilities to do scientific inquiry, the PATHWAY standard-based approach recommends that teachers who are promoting IBSE to support students to (1) learn how to identify and ask appropriate questions that can be answered through scientific investigations, (2) design/conduct investigations to collect the evidence needed to answer a variety of questions, (3) use appropriate equipment/tools to interpret and analyse data, (4) learn how to draw conclusions and think critically and logically to create explanations based on their evidence, (5) communicate and defend their results to their peers and others.

Regarding students' understanding about scientific inquiry, the PATHWAY standard-based approach recommends that teachers that effectively introduce IBSE should be able to help students understand: (1) That science involves asking questions about the world and then developing scientific investigations to answer their questions. (2) That there is no fixed sequence of steps that all scientific investigations follow. Different kinds of questions suggest different kinds of scientific investigations. (3) That scientific inquiry is central to the learning of science and reflects how science is done. (4) The importance of gathering empirical data using appropriate tools and instruments. (5) That the evidence they collect can change their perceptions about the world and increase their scientific knowledge. (6) The importance of being sceptical when they assess their own work and the work of others. (7) That the scientific community, in the end, seeks empirically based and logically consistent explanations. (8) A detailed description of all finally selected Best Practice examples tested within the framework of PATHWAY in numerous countries across Europe is provided by Bogner, Boudalis and Sotiriou [4].

16.5 Conclusions

The main conclusions of PATHWAY are the following (see also Fig. 16.2): (1) Its participation increases the teachers' knowledge base about IBSE as well as their attitude towards implementing these methodologies with students and diffusing the practices among fellow teachers. (2) The relative scarcity of pre-event knowledge on the IBSE methodologies' characteristics is a good indicator for the necessity of projects like PATHWAY. (3) Pre-service teachers welcomed PATHWAY events as an opportunity for learning about and also experiencing. (4) Effects of the event type on the teachers' responses are found, including the use of ICT for dealing with differentiated groups of students. (5) The vast amount of detailed data available for individual event types opens up the possibility to perform detailed inter-event type analysis for a large number of topics considered in the questionnaires. (6) The teachers demanded more training time, as well as including further information about the potential use of ICT. (7) Teachers were quite pleased with the content of the training, even those teachers who already had some knowledge of IBSE. (8) Teachers appreciated the possibility to take home practical and usable class-materials. (9) The participants have shown a commitment to implementing the action plans developed during the events and many have started deploying them. (10) The use of research-based instructional strategies has been shown to result in changes in teachers' practices. (11) An evaluation exercise has allowed to illustrating the improvement's persistence made in the understanding of IBSE. (12) The evaluation data can be used as a guide for the organisation of teacher training courses and a simulation exercise showing one of many possibilities to do this.

A major objective of PATHWAY was promoting and enhancing the application of active T&L methodologies in school, in particular IBSE. The seeds have been shown as already sprouting, and some areas for continuing efforts in teacher training and development as well as teachers' interactions and exchanges of resources have been earmarked. The relative scarcity of pre-event knowledge on the characteristics of IBSE methodologies is a good indicator for the necessity of projects like PATHWAY. In fact, many pre-service teachers explicitly welcomed this PATHWAY event as an opportunity for learning about, experiencing and practicing IBSE themselves. The teachers demanded more training time as well as further information about related European projects and also on the use of ICT. And, in particular, teachers appreciated the possibility to take home practical and usable class-materials.

The added value of this presented EU project encompasses the amount and origin of trainees, the diversity of trainees in formal and non-formal working areas and educational levels, the large amount of training events delivering various formats and approaches, the quantity and quality of the pedagogical materials and methodologies that have been tested successfully, and the positive response and enthusiasm from all stakeholders involved.

References

1. Asay, L. D., & Orgill, M. K. (2010). Analysis of essential features of inquiry found in articles published in the science teacher, 1998–2007. *Journal of Science Teacher Education, 21*, 57–79.
2. Beetham, H. (2007). An approach to learning design. In H. Beetham & R. Sharpe (Eds.), *Re-thinking pedagogy for a digital age* (pp. 26–39). New York: Routledge.
3. Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education, 32*, 347–364.
4. Bogner, F. X., Boudalis, A. K., & Sotiriou, S. (2013). *Best practices of inquiry-based science education. Methods and activities*. Athens: Epinoia.
5. Bybee, R. W. (2000). Teaching science as inquiry. In E. H. van Zee (Ed.), *Inquiring into inquiry learning and teaching science* (pp. 20–46). Washington, DC: AAAS.
6. Bybee, R. W., Trowbridge, L. W., & Powell, J. C. (2008). *Teaching secondary school science: Strategies for developing scientific literacy* (9th ed.). Columbus: Pearson/Merrill/Prentice Hall.
7. Conole, G. (2008). Using compendium as a tool to support the design of learning activities. In A. Okada, S. B. Shum, & T. Sherbone (Eds.), *Knowledge cartography: Software tools and mapping techniques* (pp. 199–221). London: Springer.
8. Conradty, C., & Bogner, F. X. (2011). Computer-aided learning: Unguided versus guided instruction. *ASL (Advanced Science Letters), 4*(11/12), 3310–3316.
9. Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916–937.
10. Ellis, E., & Goodyear, P. (2010). *Students' experiences of e-learning in higher education: The ecology of sustainable innovation*. Oxon: Routledge.
11. Franke, G., & Bogner, F. X. (2011). Conceptual change in students' molecular biology education: Tilting at windmills? *Journal of Educational Research, 104*, 1–14.
12. Falconer, I., Beetham, H., Oliver, R., Lockyer, L., & Littlejohn, A. (2007). *Mod4L final report: Representing learning designs*. Retrieved 14 May, 2014, from http://www.academy.gcal.ac.uk/mod4l/
13. Girwidz, R., Bogner, F. X., Rubitzko, T., & Schaal, S. (2006). Media-assisted learning in science education: An interdisciplinary approach to hibernation and energy transfer. *Science Education International, 17*(2), 95–107.
14. McLean, P., & Scott, B. (2011). Competencies for learning design: A review of the literature and a proposed framework. *British Journal of Educational Technology, 42*(4), 557–572.
15. Moskovitz, C., & Kellogg, D. (2009). Inquiry-based writing in the laboratory course. *Science, 332*(6032), 919–920. doi:10.1126/science.1200353.
16. Pöhnl, S., & Bogner, F. X. (2012). Learning with computer-based multimedia: Gender effects on efficiency. *Journal of Educational Computing Research, 47*(4), 387–407.
17. Randler, C., & Bogner, F. X. (2009). Efficacy of two different instructional methods involving complex ecological content. *International Journal of Science and Mathematics Education, 7*, 315–337.

18. Scharfenberg, F.-J., & Bogner, F. X. (2010). Instructional efficiency of changing cognitive load in out-of-school laboratories. *International Journal of Science Education, 32*(6), 829–844.
19. Scharfenberg, F.-J., & Bogner, F. X. (2011). A new two-step approach for hands-on teaching of gene technology: Effects on students' activities during experimentation in an outreach gene technology lab. *Research in Science Education, 41*(4), 505–523.
20. Sotiriou, S., & Bogner, F. X. (2005). *The pathway to high quality science teaching*. Athens: Epinoia.
21. Sotiriou, S., & Bogner, F. X. (2011). Inspiring science learning: Designing the science classroom of the future. *ASL (Advanced Science Letters), 4*, 3304–3309.
22. Sotiriou, S., Bogner, F. X., & Neofotistos, G. (2011). Quantitative analysis of the usage of the COSMOS science education portal. *Journal of Science and Technology Education, 20*, 333–346.

Chapter 17
Pedagogy as an Inquiry Approach to Teaching: Inspiring Science Educators Through CPD Webinars

Yvonne Crotty, Margaret Farren, and Martin Owen

17.1 Introduction

It would be consistent for those who wish to promote Inquiry Based Learning (IBL) in the classroom or school science laboratory to take an inquiry based stance to their own teaching practice as they integrate IBL in the classroom. Our approach to designing professional development programmes is influenced by ideas, which over time, have become key in the learning of professionals to changing and evaluating their own practice. This approach to pedagogy led to our participation in the Pathway to Inquiry-based Science Education project (2010–2013) [http://www.pathway-project.eu/] and the EU Inspiring Science Education (ISE) project (2013–2016) [http://www.inspiringscience.eu]

We recognise that knowledge and ideas generation can come from a range of contexts. Our focus is on the practical relevance of research and the concerns of practitioners in real world settings. It is in this context that we [Crotty and Farren] established the Centre for Innovation and Workplace Learning (https://www4.dcu.ie/cwlel/index.shtml) in order to connect the research and teaching, that we are doing at a national level, with our European and International projects. The Centre supports practitioners in making their unique contribution to the creation of knowledge by actively participating in decision-making processes that have the potential to transform their lives and the lives of others.

It is our experience that teachers need to be supported through Continuing Professional Development (CPD) in order to integrate e-tools and resources into the classroom. The ISE project aims to provide digital resources and opportunities for teachers across Europe and beyond to participate in CPD so that they can make science and maths education more interesting and relevant to students' lives. Through

Y. Crotty (✉) • M. Farren • M. Owen
School of Education, Dublin City University, Dublin, Ireland
e-mail: yvonne.crotty@dcu.ie; margaret.farren@dcu.ie; martinowen@mac.com

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1_17

our CPD programmes we encourage teachers to become more entrepreneurial and enterprising by taking risks, awakening their creativity and bringing new ideas into action.

In our experience, action research is an appropriate approach for practitioners as it allows them to research their own practice in order to bring about a change or improvement. It is a form of practitioner research where there is a professional intent to intervene to improve practice in line with values that are rational and just, and specific to the situation. Through the process, practitioners come to a better understanding of their practice and their influence in the situation and on others. The iterative cycles of action and reflection also allow individuals to gain a deeper understanding of the values embodied in their own practice.

In the ISE pilot study which took place between February and April 2014, we used webinars to support a group of post-primary Science teachers in Ireland, to experience the IBL approach and the range of e-tools and resources provided through ISE that supports IBL in the classroom.

17.2 Reflective Practitioners and Communities of Practice

Schön [13], viewed reflective practice as "the capacity to reflect on action so as to engage in a process of continuous learning". Dewey [7] understood reflective practice to be a form of intelligent action. Another definition states that reflective practice involves "paying critical attention to the practical values and theories which inform everyday actions, by examining practice reflectively and reflexively. This leads to developmental insight" [2].

Of particular relevance to reflective practice is Brookfield [3] who suggests that critically reflective practitioners constantly research their assumptions by seeing practice through four complementary lenses:

1. The lens of their autobiography of learners of reflective practice
2. The lens of learners' eyes
3. The lens of colleagues' perception
4. The lens of theoretical, philosophical and research literature

To become critically reflective, Brookfield believes that these four lenses allow learners (teachers) to reflect on their practice. In considering Lens 1, we support teachers to reflect back on their own experiences as a learner as we believe this provides important insight for their teaching practice. Indeed in analysing our own autobiography and exploring our own educational values we are able to draw out insights for practice.

Applying Lens 2 – through the learners' eyes. We encourage teachers to conduct research into their own practice and collect data from their students. The feedback provides a corrective steer to their practice. In Lens 3, colleagues act as critical mirrors reflecting back images of their own actions. Talking to colleagues about difficulties and ambiguities experienced in practice and involving colleagues in the research, ensures rigor in the research process. Lens 4, Theoretical literature, shows how theory can help teachers to "name" their practice by relating their experiences to the broader field of literature.

This collaborative and critically reflective approach demands a professional practice that involves a continuous communication with fellow practitioners. Lave [8] argues that learning as it normally occurs is a function of the activity, context and culture in which it occurs. This contrasts with most university learning activities which involve knowledge which is often abstract and out of context.

17.3 IBL and the National Situation in Ireland with Regard to Science and Maths Education

In the Strategy for Science, Technology and Innovation Report [5], the Irish Government recognised the need to significantly change how science is taught in post-primary schools. The strategy report stresses the need to focus on investigative approaches, problem-solving, the assessment of practical work and the 'embedding of key skills and ICT' [p. 51] and providing 'enhanced internet based support materials and resources for teachers' [ibid]. There is now a growing awareness among post-primary science teachers of the need for an inquiry-based approach to be incorporated into science teaching.

An inquiry approach is now more explicitly stated in the new Junior Certificate course (12–15 year olds).

The current Junior Certificate Examination will be replaced by a new examination called the Junior Cycle Student Award. This examination will also be completed by students after 3 years of second level study, 13–15 year olds. It will be introduced on a phased basis and students entering second level education from 2015 onwards will study the new Science Curriculum and the first certification will be in 2018.

While details of the actual new curriculum have not yet been published a lot of important detail has been published in the Department of Education and Skills document "A Framework for Junior Cycle" [6].

The document from the DES lists eight principles for the Junior Cycle and these principles underpin twenty- four Statements of Learning. An examination of some of these Statements of Learning shows strong support for Inquiry-Based Learning:

17. devises and evaluates strategies for investigating and solving problems using mathematical knowledge, reasoning and skills.
18. observes and evaluates empirical events and processes and draws valid deductions and conclusions.
24. uses technology and digital media tools to learn, communicate, work and think collaboratively and creatively in a responsible and ethical manner.

Table 17.1 Six Key Skills of Junior Certificate

Key Skill	Elements
Managing myself	*Being able to reflect on my own learning*
	Using digital technology to manage myself and my learning
Staying well	*Discussing and debating*
Communicating	*Discussing and debating*
Being creative	*Stimulating creativity using digital technology*
Working with others	*Learning with others*
	Working with others through digital technology
Managing information and thinking	*Gathering, recording, organising and evaluating information and data*

The listed principles show some of the key elements of inquiry, and evidence the move away from a content-based curriculum. Six key skills will be embedded in each Junior Cycle subject, including Science. An analysis of these key skills and some of their elements, as outlined in Table 17.1, show strong support for an inquiry based approach to learning.

It is planned that the new Junior Cycle will have a school based approach to assessment which will focus on both the process and product of learning through a combination of students' work during the final 2 years of the cycle and a final examination. The final assessment will be just one element of a broader school based approach to assessment.

With regard to the teaching of Maths in post-primary schools in Ireland, Project Maths was introduced in 2008 as a result of the National Council for Curriculum and Assessment review of mathematics education [9, 10]. The aim is to increase the number of students taking Higher Level mathematics at Leaving Certificate (16–18 year olds). Project Maths enables students to appreciate how mathematics relates to real life and the world of work, and to apply their mathematical knowledge and skills to solve familiar and unfamiliar problems [Project Maths Development Team 2008] [11]. In light of these developments in inquiry-based learning (IBL), there is a need to harness the affordances of technology in order to provide CPD in IBL to teachers.

17.4 Continuing Professional Development

An OECD [12] (p. 50) Teaching and Learning International Survey (TALIS), reported the following activities as formal types of CPD:

- Courses/workshops
- Education conferences or seminars
- Qualification programme (*e.g.* a degree programme)
- Observation visits to other schools

- Participation in a network of teachers formed specifically for the professional development of teachers
- Individual or collaborative research on a topic of professional interest
- Mentoring and/or peer observation and coaching, as part of a formal school arrangement.

Informal types of CPD were listed as:

- Reading professional literature (*e.g.* journals, evidence based papers, thesis papers)
- Engaging in informal dialogue with peers on how to improve teaching

The usual provision of CPD in Ireland has tended to be more skills based, 'one-shot, knowledge transfer model' [4] (p. 187). This contrasts with research from Anderson [1] who points out that CPD for inquiry-based teaching needs to take into account teachers' beliefs, values and understandings in practical contexts that relate closely to teachers' current practice.

In the pilot stage (year 1), the ISE team in Ireland recruited 21 Science teachers to join the ISE project and take part in the participatory engagement activities, in the form of webinars. A webinar is a seminar that takes place over the internet and it allows people from different locations to take part in the conference rather than having to travel to attend the seminar/workshop. Participating teachers from different locations in Ireland participated in these live online events (webinars).

The webinars have supported the following ISE activities:

1. Introduction to the ISE Action Plan and Erasmus funding opportunities
2. Engaging teachers and their school in the ISE project
3. Introduce teachers to IBL
4. Introduce teachers to Narratives (class plans)
5. Introduce teachers to e-Tools and Resources

In one of the webinar sessions Marian Lowry, a post-primary Science teacher who was undertaking an action research inquiry as part of the Masters in Education and Training Management (eLearning) programme narrated her experience of using IBL in the classroom. In preparation for the webinar she undertook the task of writing a narrative to explain how she implemented a junior science inquiry lesson using the ISE narrative template. A narrative is an illustration of how an inquiry-based lesson supported by digital interactive e-Learning tools can be implemented in practice.

The informative experience of authoring the narrative helped the post-primary teacher to become more keenly aware of how digital technologies can support an IBL approach when properly aligned with educational goals. Using this framework provided her with a better understanding of the scientific processing skills necessary for students to seek answers to their own questions. It helped her to organise the inquiry learning activities, find areas of focus, experiment with different ideas and set realistic goals. This new approach to planning enabled her to be more student centered in her thinking and also provided a guide to reflect on her own teaching strategies.

The ISE narrative integrated a student initiated, inquiry approach to her teaching style. The narratives enabled her to develop students' thinking and to use technologies in a meaningful way. Through reflection on the whole process she realised that this simple planning strategy can help guide effective teaching by providing a framework for a traditional teacher to follow as they develop the skills and confidence to teach IBL. In addition this approach provides a means of scaffolding and guiding teachers as they facilitate a student centered technology-rich classroom by helping them to work through the implementation of the inquiry-based lesson. With a clear focus on the learning outcome, the teacher can plan their lesson using the ISE narrative template to identify the best way to reach the desired goal.

In undertaking to research the writing of the narrative, the post-primary teacher examined her own practice of using IBL with narratives. She used her own reflections on practice to structure a CPD webinar with a group of ISE Science teachers in order to explain how they could integrate IBL into their pedagogy through the design and implementation of inquiry based narratives.

17.5 Conclusion

It is vital that providers of CPD take account of social practices and collaborative learning approaches. At the Centre for Innovation and Workplace Learning, we take a critical perspective on the development of pedagogy and believe that it is important that teachers learn to examine their own professional practice within a community of practice. This social approach to learning should also extend to the selection of technology and how it is used to facilitate learning.

References

1. Anderson, R. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1–12.
2. Bolton, G. (2010). *Reflective practice, writing and professional development* (3rd ed., p. xix). California: SAGE publications.
3. Brookfield, S. (1998). Critically reflective practice. *Journal of Continuing Education in the Health Profession, 18*(4), 197–205.
4. Conway, P.F., Murphy, R., Rath, A., & Hall. K. (2009). *Learning to teach and its implications for continuum of teaching education: A nine-country cross-national study, Teaching Council of Ireland*. Accessed http://www.teachingcouncil.ie/_fileupload/Publications/LearningToTeach-ConwayMurphyRathHall-2009_10344263.pdf
5. Department of Education and Science. (2006). *Strategy for science, technology and innovation report*. Accessed http://www2.ul.ie/pdf/35659989.pdf
6. Department of Education and Skills. (2012). *A framework for junior cycle*. Accessed http://www.education.ie/en/Publications/Policy-Reports/A-Framework-for-Junior-Cycle-Full-Report.pdf

7. Dewey, J. (1933) *How We Think. A restatement of the relation of reflective thinking to the educative process* (Rev. edn.), Boston: D. C. Heath.
8. Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.
9. National Council for Curriculum and Assessment. (2005, October). *Review of mathematics in post-primary education.* Retrieved February 15, 2012, from http://www.ncca.ie/en/Publications/Consultative_Documents/Review_of_Mathematics_in_PostPrimary_Education.pdf
10. National Council for Curriculum and Assessment. (2006, April). *Review of mathematics in post-primary education – report on the consultation.* Retrieved April 20, 2012, from http://www.ncca.ie/uploadedfiles/mathsreview/Maths_Consult_Report.pdf
11. National Council for Curriculum and Assessment. (2008, February). *Project maths: developing post primary mathematics education.* Retrieved June 1, 2012, from http://www.ncca.ie/uploadedfiles/publications/vacancies/project%20maths%20overview.pdf
12. OECD. (2009). *Creating effective teaching and learning environments: First results from TALIS*. Accessed http://www.oecd.org/edu/school/creatingeffectiveteachingandlearningenvironmentsfirstresultsfromtalis.htm
13. Schön, D. (1983). *The reflective practitioner, How professionals think in action*. NewYork: Basic Books.

Conclusion

In an effort to shed light and realize an in-depth exploration of the multifaceted nature that characterizes Science and Technology education, we endeavored to adopt a holistic and all-inclusive approach that involves and relies on methodological contributions and different approaches that are encountered in various sciences: computer science or information and communications technology, psychology, cognitive science, sociology and neurosciences. This fundamental interaction and connectivism among different scientific fields is the focal issue and main objective of the book, which investigates their potential and educational affordances for the construction of new developments in science and technology education.

Intensive research has revealed and indicated that ICT – Information and Communication Technology – can provide the possibility to support education for knowledge age skills in two ways which are distinct but compatible to each other. Exploratory learning environments, including games and simulations, can stand as a ground basis for the representation of abstract ideas and their metamorphosis into concrete and manipulable objects-ideas. And yet, during the last decade, the number of breakthrough digital artifacts produced for the assistance of students in the development of learning scientific and technological notions through their manipulation as expressive and exploratory tools remains quite low. Research, though, has illustrated certain ways for students to adopt an enquiry scientific attitude towards such subjects, which will help them strive for rigor and insight and develop the necessary skills that will enable them to both abstract and generalize. On the other hand, ICT can modify and expand learning with the adoption of the Computer-Supported Collaborative Learning (CSCL) approach. In computer-supported collaborative environments, users are engaged in reflective processes and argumentation practices; enhanced and facilitated to acquire skills in collectives. The computer-supported learning dialogues amplify the range of learning resources available for users and provide new possibilities for the development of knowledge age skills.

Inquiry-based learning has penetrated in the modern didactics that guide and inform science and technology education curricula. It is a highly structured and

M. Riopel, Z. Smyrnaiou (eds.), *New Developments in Science and Technology Education*, Innovations in Science Education and Technology 23,
DOI 10.1007/978-3-319-22933-1

thoughtfully designed endeavor which has the potential to enhance students' engagement in knowledge inference and in-depth processes and enable them to track their cognitive development. By setting the context for developing hands-on, research-based procedural tasks, it shapes and defines an instructional frame that bridges the gap between the learning process and authentic scientific practices. Inquiry-based learning considered and structured as an instructional process manages to promote students' learning by accommodating their conceptual transformations through a rational-based, conceivable and scientifically informed tracking of their thinking and learning.

Intuitive science and conceptual change have also been indicated as key factors in science and technology education. During the last decades, researchers in science education have identified several explanations to students' representations (or misconceptions, etc.) that address a set of difficulties that students encounter in science education. Intuitive interference of salient variables while logically processing the relevant variables has been identified as a major factor responsible for students' persisting misconceptions and failure to construct meaningful and solid scientific concepts. Neuroeducation or neuroscience field techniques are currently applied in educational research to shed light to these complex cognitive processes and provide us with techniques that will facilitate conceptual change.

The exploration of motivation as a cognitive enhancing factor is an example of the new research directions that characterize science education. Researches investigating the factors that affect interest and attitude have provided us with valuable findings that bring up new perspectives in the field of science and technology education. The implementation of creative strategies in the form of hands-on learning experiences and the learning to learn together collaborative approach have been identified as crucial issues that require further research towards the aim of enhancing the motivation factor.

Assessment is also considered a fundamental issue in the formation of the quality of science education and technology. Within the context of educational reforms worldwide, there has been noticed and highlighted a shift of focus from assessment that focuses solely on the acquisition of knowledge/learning (assessment of learning) to assessment of the effective implementation of skills in various environments (assessment for learning). This tendency has been triggered by the adoption of new pedagogical theories and their implementation in the learning process. The pedagogically informed assessment is no longer treated as an accumulative process and requires skilful and trained educators to effectively and reflectively develop and apply it in their practices, considering the different learning contexts and student needs. By adopting such an approach, emphasis is given to the cognitive procedure rather than the outcome and pedagogically informed assessment strategies are required for the production of reliable, valid and most of all useful and reflective information.

Towards addressing the aim of the book which is the exploration of pedagogically updated practices and approaches in the teaching of science concepts and the elaboration on future challenges and emerging issues in Science and Technology Education, we have included in the book chapters that profoundly elaborate on important aspects of science and technology education research. By pointing out on new research directions, we manage to inform educational practices and bridge the gap between research and practice, providing information, ideas and new perspectives. The book aims to inform as well as to promote discussions among scientists, researchers, teachers and students who are generally involved in science and technology but also in the fields of science education, didactic science, ICT in education, modern pedagogy and psychology, neuroscience and neuroeducation.