Chapter 8
Technology-Enhanced Learning in Science

Eleni A. Kyza, Sibel Erduran and Andrée Tiberghien

Abstract This chapter investigates the supportive role of new technologies in science learning. The first part presents the theoretical underpinnings of technology-enhanced learning (TEL) in science, framing TEL in the context of current socio-cultural view of science learning as inquiry. The second part discusses the potential of TEL, which is organized around the potential of learning technologies to make science learning authentic and to provide the tools to sustain engaged participation in making sense of the physical and the natural world. Examples of learning technologies are presented and discussed.

Keywords Learning technologies · Science education · Inquiry

8.1 Introduction

As new technologies are increasingly being portrayed as pivotal to reform initiatives, the Kaleidoscope Network of Excellence was formed with the explicit goal of exploring the future of technology-enhanced learning (TEL). In this chapter, we discuss the supportive role of TEL in science education. The argument is unpacked by discussing the theoretical underpinnings of technology-enhanced science learning and the potential of new technologies for learning in science education.

We begin our discussion with a theoretical framing of technology-enhanced learning in science. The first issue concerns the relation between cognitive, epistemological, and sociocultural accounts of knowledge growth in science learning. Substantial amount of research has investigated children's cognitive development (e.g., Carey, 1985), theory change in science (e.g., Giere, 1991), and the sociocultural foundations of learning (e.g., Anderson, 2007). An important implication is that cognitive, epistemological, and sociocultural criteria and conditions that drive scientific theory change might be useful for supporting students' science learning in

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E.A. Kyza (✉)
Department of Communication and Internet Studies, Cyprus University of Technology,
Limasso, Cyprus
e-mail: Eleni.Kyza@cut.ac.cy

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the classroom and can guide the design of technology-enhanced learning environments. We then turn our attention to the potential of new technologies to support learning in science, and we contextualize our discussion with respect to the learning goals related to scientific inquiry. We conclude by discussing the contribution of technology-enhanced environments to promote science learning.

8.2 Theoretical Framing of Technology-Enhanced Learning in Science

There is worldwide dissatisfaction with the quality of science education (Bransford, Brown, & Cocking, 1999; Osborne & Dillon, 2008). Among others, Bransford and colleagues point to the incongruence between the state of knowledge about science learning and the expectations on learning goals in the current education system in the United States, while Osborne and Dillon emphasize that there are problems with both the nature and the structure of science education efforts in Europe. These authors argue that the state of science teaching today is far behind current societal expectations and needs of a scientifically literate citizenry.

A fundamental tenet of modern learning theories is that different kinds of learning goals require different approaches to instruction and that new goals for education require changes in opportunities to learn. Reform proponents call for a socio-constructivist, learner-centered approach to science education, one that places emphasis on inquiry learning as the means to learn scientific content and acquire life-long skills to enable them to reason scientifically (also see Chapter 2). Scientific literacy has been defined as “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities” (National Research Council, 1996, Chapter 2). In this chapter we argue that scientific literacy, which includes understanding of the scientific concepts and skills and understanding the nature of science, has to be a primary goal for inquiry-based science learning and teaching today and that new technologies have the capacity to support the attainment of this goal.

One’s theoretical perspective about how science learning happens influences the design and implementation of technology-enhanced learning. The question of the relation between learning theories and the design of technology-enhanced learning is complex. There are many theoretical perspectives in science learning while some components of the design of specific learning software, or of an effective teaching sequence, may be compatible with different aspects of the theoretical components (Design-Based Research Collective, 2003).

Recently several review papers have appeared on general orientations of research in science education (Anderson, 2007), on science learning (Scott, Asoko, & Leach, 2007), and on a historical perspective of an important research stream of science learning, conceptual change (diSessa, 2006). It appears that several traditions or perspectives emerge from these reviews, each one of them having the capacity of changing the design and role of learning technologies in the classroom, and thus affecting science learning. Leach and Scott (2003) discuss individual and sociocultural views as the two main theoretical strands in science learning. The individual strand, which has its main roots in Piagetian constructivism, has been described using such terms as "conceptual change tradition" (Anderson, 2007) and "cognitive approaches" (Scott et al., 2007). A distinctive approach of this current is its focus on the role of the *individual* students' prior knowledge which is frequently in conflict with the conceptual knowledge to be acquired. This conflict is often referred to in the history and philosophy of science in terms of scientific revolution proposed by Kuhn (1970). A seminal paper by Posner, Strike, Hewson, and Gertzhog (1982) proposed that

> the conditions needed for a major change in thinking with a scientific field (such as the shift from an Earth-centered to a Sun-centered model of the solar system) were considered analogous to the conditions needed to bring about accommodation or conceptual change in individual learners can occur. These conditions are that a learner must first be dissatisfied, with existing ideas and then that the new ideas must be seen as intelligible, plausible, and fruitful (pp. 35–36).

Similarly, Anderson (2007) has emphasized that this current on conceptual change explains "the failure of students to learn the science that they are taught in schools in terms of hidden conflicts – conflicts between scientific conceptual frameworks and their own experience" (p. 14).

The second theoretical strand is the *sociocultural* one, which has its roots in Vygotsky's work. As Sutherland, Lindström, and Lahn (Chapter 3) discuss, the sociocultural perspective situates learning in human practice and views this activity as mediated by tools and actions. The social context plays a major role in learning, without neglecting the role of individual with the process of internalization. The view of scientific knowledge in the sociocultural perspective is different from that of the conceptual change perspective: "in contrast to conceptual change researchers' emphasis on scientists' dialogues with nature, sociocultural researchers focus primarily on scientists' dialogues with people" (Anderson, 2007, p. 18). The sociocultural theory of learning has been pivotal in developing research on computer-supported collaborative learning environments, as well as on focusing the research on the interacting agents in any learning situation which, according to this perspective, can facilitate or hinder learning. The idea here is that tools are objects to think with and that they inevitably and fundamentally shape human thoughts, discourse, actions, and interactions; the latter is the perspective that we adopt in this chapter, as we examine the role of technology-enhanced learning in science.

The case of visual model is particularly illustrative of this gap between grand theories and design of learning technologies to be used in classrooms. The multimodality, not only of communication between people but also of science, involves multiple semiotic systems. The hypothesis on the role of this multiplicity of semiotic systems in learning has been emphasized by tenants of "science concept learning as participation" (Lemke, 1990) and by those of cognitive approaches (Duval, 1995). Then, this hypothesis leads the designer to take into account the different representations of concepts like force, acceleration, or models like particulate model of matter, which have several components: natural language, geometric and algebraic, drawings, and then constrains the design of environment (Tiberghien, Gaidioz, & Vince, 2007). Thus, the theoretical framing of the designer shapes the final design, which in turn mediates and can modify the learning process and outcomes.

8.3 The Role of New Technologies in Science Learning

In the last few decades, new technologies have gradually claimed a significant role in supporting the goals of science learning, as they are described in key science education documents worldwide (American Association for the Advancement of Science, 1993; National Research Council, 1996; Organisation for Economic Co-operation and Development, 2004). Moving beyond technological tools that support factual learning and memorization and the reinforcement of basic skills, this chapter focuses on learning technologies which give students the tools to engage in meaningful science learning. TEL environments can support the gradual development of higher-order skills, such as critical thinking and problem-solving in inquiry-based learning, alongside the development of domain-based reasoning. To this end, new technologies become cognitive tools, which are tailored specifically to meet the needs and learning goals of science learners (Songer, 2007). Songer makes a distinction between digital tools, such as scientific data available on the web, and cognitive tools, which she defines as "computer-available information . . . presenting focused information specifically tailored for particular learning goals on a particular topic of interest for learning by a particular target audience" (p. 476). Agreeing with the definition given by Songer, we also use the term "learning technologies" to describe those new technologies that become cognitive tools in the hands of the learners to facilitate learning in science.

Learning technologies can extend what the learner can do on their own (Hutchins, 1995) and enable them to engage in observing, manipulating, and examining the natural world around them in a way that would be otherwise extremely challenging, time consuming, or plain unattainable. In this context, learning technologies serve multiple goals: first, they support the acculturation of the learner into the practices of science, by giving them access to tools that can help them engage in scientific inquiry processes that resemble the ones used by practicing scientists. Second, acknowledging that the development of expertise takes time and that learners are novices in the scientific practices they are asked to engage with, scaffolds in the learning technologies can help learners more easily engage in higher-order reasoning. Thus, learning technologies can be seen as contributing to making science learning authentic and supporting the development of scientific literacy. Together, these efforts can contribute to students' appreciation and understanding of the nature of science.

In the next section we present some representative examples of learning technologies to support inquiry-based learning in science. This section is not meant to be a comprehensive overview, but rather it can be seen as an illustration of the breadth of tools currently available in science education. The section discusses four areas of technology's contribution: tools to support meaningful science learning, tools for reflection, argumentation, and communication of ideas, tools to support communities of learners, and tools to support teaching and learning.

8.3.1 Tools to Support Meaningful Science Learning

Many researchers argue that science learning should consist of authentic learning activities which resemble the practices of the scientific community (Bransford et al., 1999; Brown, Collins, & Duguid, 1989; Chinn & Malhotra, 2002; Edelson, 1997; Lee & Songer, 2003) and allows students to experience scientific inquiry. This often means that students are asked to solve problems that are complex and which do not have an easily perceivable solution. Perhaps the primary goal of science curricula today ought to be the creation of the conditions for what Chinn and Malhotra (2002) call "epistemologically authentic inquiry", in which students engage in targeted scientific inquiry practices that enable the development of reasoning that resembles that of scientists. Some of these practices (as also discussed in Chapter 2) are solving meaningful and open-ended problems, interpreting and analyzing primary data, modeling ideas and phenomena, and creating evidence-based arguments and explanations.

New technologies are an indispensable commodity to modern science. As such, they are essential to learning science as they extend students' capacity to engage in theory testing and the construction of evidence-based explanations. Almost all scientific domains have been tremendously supported by the presence of such tools, the geosciences and biology being just two examples. According to Edelson (1997) the scientific practice consists of three key categories of features: attitudes, tools and techniques, and social interaction. In Edelson's categorization the environments that afford the development of authentic scientific attitudes are those in which students experience the uncertainty of the scientific knowledge and in which students are committed to systematically pursuing their research questions. By providing learners with open-ended technological tools they are encouraged to engage in practices resembling those of scientists, having at their disposal a variety of tools and techniques which they can use to test their developing theories.

Furthermore, the use of scaffolding, an idea borrowed from Vygotsky's (1978, 1986) work and present in the design of learning technologies, can support the gradual acculturation into the terminology, concepts, and practices of science. As part of this effort to make school science more authentic, and since scientific practice and technology are dynamically linked, researchers have created scaffolded technological tools to enable students to engage in practices similar to the ones of scientists, by adapting the technology to serve the needs of the novice learners. With their multimodal, interactive, and dynamic representations, new technologies have the capacity to motivate learning by helping create situations in which the learners undertake the solution of authentic science problems and use tools that enable them to take responsibility over their own learning. This motivating aspect of new technologies is crucial considering the declining interest of young students in the sciences (Sjøberg & Schreiner, 2006). Scaffolded environments can help bridge the learner's current state of understanding and the scientific mode of thinking, helping learners grow within their zone of proximal development (Vygotsky, 1978). In addition, technology can foster inquiry learning in science by serving as a metacognitive tool, helping structure the students' task, facilitating the articulation and externalization of students' understanding, and scaffolding the development of the learner as a self-regulated inquirer (Linn, Davis, & Eylon, 2004). Finally, technological tools can support the development of scientifically resonate attitudes and facilitate the communication among peers and between learners and teachers.

We next present an overview of such scaffolded tools, organized in the following five categories: scientific visualization tools, databases, data collection and analysis tools, computer-based simulations, and modeling tools.

a) *Scientific visualization tools.* This category reflects the adaptation of expert tools used by practicing scientists so that young learners can engage in the analysis of complex, real-world data sets. For example, *MyWorld GIS* (Edelson & Russell, 2006) is a scaffolded interface for a database that automatically represents geographic data in visual modes. The possibility to have multiple representations on-demand with a click of the mouse, along with the other analytical tools, can support students' experimentation with important ideas about science.
b) *Databases*. Oftentimes in science learning a teacher may choose to focus on particular aspects of science practices, in order to foster deep understanding about those practices. This is the case of working with existing data sets, usually collected in digital databases either on a stand-alone computer or off the Internet (Chinn & Malhotra, 2002). In some domains, inquiry cannot be conducted without access to such databases, as is the case with historic data that need to be compared and contrasted over large periods of time in order to discern patterns and reach valid conclusions. Natural selection is one such important concept, which can be facilitated by accessing scaffolded databases such as the one in the *Galapagos Finches* environment (Reiser et al., 2001). It is important to note that such environments not only give access to data but also structure the learning environment so that the learner is subtly guided and constrained in the choices they can make. This is an important role of scaffolding, which can thus be seen as facilitating the sense-making process (Quintana et al., 2004).
c) *Data collection and analysis tools.* Learning technologies can also facilitate the data-gathering and analysis aspect of scientific practice. Examples of such technologies are probes, sensors, or handheld computers which make the collection of real-time data from the local environment possible – these data can then be used to answer a multitude of research questions. (For instance, sensors usually found in many high school classrooms today can facilitate the collection of data on temperature, salinity, motion paths, voltage, etc.) These data are then automatically and dynamically represented in graphical or numerical form, can be digitally stored for further analysis, and can contribute to conceptual understanding. The

Kids as Global Scientists (Songer, 1996) environment is one such example of a technology that allows the mining of online data from the Internet, which are then available to students for comparisons and analysis. Furthermore, such tools can help students answer problems of local importance, such as the quality of the water in the river near them, and can thus enhance students' motivation and meaningful engagement with science.

d) *Computer-based simulations.* Computer-based simulations are powerful tools that can support conceptual understanding (de Jong, 2006; Zacharia, 2007) by allowing experimentation to answer "what if" questions. A main affordance of computer-based simulations, as compared to other simulation activities, is that they allow manipulation of ideas overcoming issues such as safety, access to physical resources, and temporal constraints (Hofstein & Lunetta, 2003). In science education, simulations are based on scientific models and provide learners with the tools to systematically observe and manipulate central parameters of the phenomenon under examination (van Joolingen & de Jong, 1991). Examples of research-informed computer-based simulations environment include *SimQuest* (van Joolingen & de Jong, 2003), *Co-Lab* (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005), and *BioWorld* (Lajoie, Lavigne, Guerrera, & Munsie, 2001). Currently, there are many simulation environments to help teach a multitude of topics in disciplines such as physics, chemistry, biology, as well as environments that adopt an approach of integrated learning. For instance, *SimQuest* includes several simulations that can support learning about biology concepts and processes, such as bacteria growth, physics concepts such as Newtonian mechanics, and learning about socio-scientific topics such as waste water technology.

e) *Modeling.* Another category of learning technologies is that of modeling tools. Modeling is seen as a core scientific practice and as such, modeling is advocated as a valuable pedagogical approach to learning science (Coll, France, & Taylor, 2005; Gilbert, 2004; Halloun, 2006; Schwarz & White, 2005; Sensevy, Tiberghien, Santini, Laube, & Griggs, 2008). Similarly to simulations, modeling software supports the systematic manipulation of variables for testing theories and developing conceptual understanding. Increasingly, computer-based modeling environments also embed models that can be inspected and used as the basis of new or improved models, but which can also be run as simulations. Unlike simulations, which most frequently run on a black-box design, modeling tools such as *Model-It* (Jackson, Stratford, Krajcik, & Soloway, 1994), *STELLA* (Richmond & Peterson, 1990), *ModellingSpace* (Dimitracopoulou & Komis, 2005), *ThinkerTools* (Frederiksen & White, 1998), *NetLogo* (Wilensky, 1999), and *Stagecast Creator* (Smith & Cypher, 1999) afford the creation and manipulation of models by the users themselves, thus adopting a glass-box design (Wilensky, 2001). Glass-box environments are inspectable and modifiable by the user and can, thus, invite theory-based experimentation and reflection. In response to the identified learning challenges, designers have developed modeling software that allows users to engage in qualitative modeling (e.g., *Model-It*) and making the pedagogical approach amenable to younger learners (e.g., *Stagecast Creator*). Continuing technological development has allowed learners to model at different levels (micro and macro), and even engage in participatory modeling activities, such as the ones provided by the networked environment of *NetLogo*.

8.3.2 Tools for Reflection, Argumentation, and Communication of Ideas

Learning technologies present learners with an increasing variety of tools to conduct scientific investigations. Such technologies are scaffolded, in that the designers have gone through a process of identifying developmental and other learning obstacles and have customized or adopted the technology so that the learning activities are within the realm of the intended target users. However, even after a motivating context has been setup and after the tools are made available, research shows that learners need further support to engage in inquiry. The nature of this support can be regulative and organizational or supportive of reflective inquiry. Examples of learning technologies which can offer support to help learners manage the investigation process (Quintana et al., 2004) include *SYMPHONY* (Quintana, Eng, Carra, Wu, & Soloway, 1999), *KIE/WISE* (Linn, Davis, & Bell, 2004a), and the *Progress Portfolio* (Loh et al., 1998).

Reflective inquiry practices that bridge the local inquiry activity with important scientific ideas are another area that can be supported through the use of learning technologies (Davis, 1998; 2003; Linn, Davis, & Eylon, 2004; Loh, 2003). For instance, several tools within *WISE* can support students' building of arguments (Bell & Davis, 2000; Linn, 2003); *Belvedere* (Suthers, 2003) supports students' construction of evidence-based arguments, while tools like *ExplanationConstructor* (Sandoval, 1998) support disciplinary explanation building. *STOCHASMOS* (Kyza & Constantinou, 2007), a web-based learning and teaching platform, provides scaffolding for supporting students' reflection-in-action about the processes and products of inquiry.

8.3.3 Tools to Support Communities of Learners, Extending Beyond the Science Classroom

The idea of creating communities of learners is appealing to science education, as it has the potential to support the appropriation of scientific practice as an essentially collaborative culture. This pedagogical approach is also grounded in the sociocultural paradigm of learning and teaching as it emphasizes learning occurring in a culture of participation in community-important activities (Rogoff, Matusov, & White, 1996). Learning technologies, such as the ones described in the previous pages, are well suited to the sociocultural perspective of learning as they provide students with the tools to not only talk science but also engage in science. The Internet has extended access to data and tools to support synchronous and asynchronous communication between learners, and learners and experts (Linn, Davis, & Bell, 2004b). Environments such as the *Knowledge Forum*, and its precursor, *CSILE* (Scardamalia & Bereiter, 2006), provide powerful tools for community knowledge building.

8.3.4 Tools to Support Teaching and Learning

Learner needs vary across several dimensions such as time and locale. Stepping away from the textbook as a rigid and authoritative source of information it is important to support teachers in authoring or customizing learning environments to support their students' needs. New technologies can provide the tools and the guidance needed to support this customization (Baumgartner, 2004). Environments such as *WISE* (Linn, 2003), *STOCHASMOS* (Kyza & Constantinou, 2007), and *SimQuest* (van Joolingen & de Jong, 2003) offer scaffolded authoring tools to support teacher adaptation of existing digital materials and the creation of new materials tailored to specific needs. These efforts have the potential to support student motivation and learning at the local level of the classroom while also supporting teachers' professional development.

8.4 New Developments in Technology-Enhanced Learning in Science

When we speak of technology-enhanced learning in science we are, in fact, speaking of a great variety of cognitive tools that can support many different aspects of science learning. New projects developing out of work supported by Kaleidoscope are examining the potential of new, open learning environments that integrate interoperable tools to support most of the goals already described as the primary areas of contribution of new technologies. Some state-of-the-art resources include open-source software, the customization of the learning environment by the user, and technologies for increased participation, such as video games, wikis, and blogs. For instance, developing video games for science learning is quickly becoming popular, even though research on these technologies is still nascent (Annetta, Cook, & Shultz, 2007). Another type of technology that is increasingly becoming popular is multi-user, virtual environments (MUVEs), such as *River City* (Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005), in which learners access a virtual world, interact with digital objects, and collaborate to solve problems. Other examples of new ground-breaking work include project *CIEL* (van Joolingen, de Jong, & Manlove, 2007) and the *Scalable Architecture for Interactive Learning* (SAIL) framework (Slotta, 2005). This work, also described in van Joolingen and Zacharia (Chapter 2), foregrounds the development of what is promising to be more flexible, open-source learning environments, which will allow learners ease of navigation and use of the affordances of learning technologies more consistently over a longer period of time.

8.5 Concluding Remarks

In this chapter we discussed the potential of learning technologies to support learning and teaching in science. Part of our discussion has been organized around the potential of new technologies to support important aspects of inquiry-based science learning such as contributing to the development of scientific reasoning skills, creating opportunities for authentic learning and providing the tools to engage in such learning, and promoting conceptual understanding. We have presented some representative examples of new technologies in support of these science education goals, whose development was evidence-and theory-based.

Traditional science classrooms do not support students' participation in scientific inquiry, in general, and in particular aspects of inquiry such as theory-evidence coordination (Erduran & Jimenez-Aleixandre, 2008; Siegel, 1995). Rather, traditional classrooms emphasize students' acquisition of conceptual outcomes of science – the declarative knowledge. Procedural knowledge (or knowledge of strategies, heuristics and criteria that justify and enable knowledge growth) is typically overlooked. Our understanding is limited with respect to the actual impact of new technologies on the above-mentioned aspects of science learning. The extent to which technology supports students' engagement in activities and modes of thinking that enable knowledge growth in scientific inquiry is of tremendous interest to science education research.

In discussing the role of TEL in science we believe we should advance questions such as the following: As science educators, what aspects of science in general and scientific inquiry in particular are supported by new technologies? How do technology-enhanced science learning environments promote science learning? What evidence is there for the effectiveness of technology-based instructional approaches in the learning of science? These questions not only are critical to ask at a time when TEL is increasingly playing a major role in educational settings but also offer an exciting challenge in application to everyday science classrooms. Dillenbourg, Järvelä, and Fischer (Chapter 1) discuss the "myth of media effectiveness", which they explain as the expectations created each time a new technology is introduced in education. Indeed, the advent of computer technologies has sparked many debates about their effectiveness to support learning. However, as research indicates, new technologies can be catalytic in supporting learning but they cannot, merely by their use, lead to better learning outcomes. Issues of student and teacher motivation, task setup, the choice of pedagogical approach, and the dynamics between collaborating peers are all pieces of the puzzle we call learning. Without understanding how the pieces of the puzzle fit together we cannot, as of yet, fully understand the potential of new technologies to reform science education. New technologies for participatory and collaborative design and learning emerge at an increasingly rapid pace, and as they do we see improved tools that are better aligned with social constructivist pedagogies. When examining the use of such technologies it is crucial that one considers the learning environment in which they are embedded and the role of the other contributing participants, such as the teacher, peers, and activity structures. In order for key science learning to occur, these different participants should work synergistically (Tabak, 2004).

Decades of classroom-based research has resulted in the clarification of two main goals for science education. On the one hand, there is the goal of education of the scientists for careers related to science. On the other hand, there is the education of the general public for informed citizenship where science is an integral aspect of everyday life. More than anything else we see technology as a tool to support human activity, and as such, the primary considerations about their use should be on whether they afford, scaffold, and encourage mindful and meaningful learning. Technology-enhanced learning approaches hold the potential to contribute centrally to both goals of science leaning and to the design of learning environments that are consistent with the cognitive, epistemological, and sociocultural framing of science learning.

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