Technology-Enhanced Teacher Education for 21st Century: Challenges and Possibilities

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Introduction

In his introduction to the edited book “The Emperor’s New Computer: ICT, Teachers and Teaching”, Di Petta (2008) challenged us to look beyond the “hype and fashion” of information and communications technology (ICT) through a thorough examination of what ICT can do for improving student learning (p. 2). In particular, he called on “pragmatic re-visioning of the fable of the Emperor’s New Clothes, looking behind the fashionable masks and costumes of ICT and examining how information and communication technologies affect the complex process of human interconnection known as teaching and learning” (p. 2). The ideas suggested in the book have significant ramifications for examining the current state of educational technologies’ implementation in Science, Technology, Engineering, and Mathematics (STEM) education.

Almost half a century has passed since computers first began entering North American public schools and educational technology visionaries and thinkers like Alan Kay (1987) and Seymour Papert (1980) began exploring computer-assisted STEM learning. Their focus was on how people learn *with* technology and what technology can do that cannot be achieved otherwise. Nevertheless, powerful political, corporate, and educational forces, coupled with the endless barrage of new educational gadgets, devices, and software, propel many educators to continue looking for *the perfect technological solution* to the old educational problems, while ignoring the importance of pedagogically-driven implementation of these technologies. The focus on purely technological solutions divorced from solid educational research that will identify the pedagogical problems to be solved and then drive the development of technologies to solve these problems significantly diminishes the pedagogical effects of these innovations. Kay (1987) referred to this issue

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as “a technological tail wagging a pedagogical dog”. In this chapter we raise and examine the *what, why,* and *how* questions in the context of technology-enhanced STEM teacher education. These are key pedagogical questions that we need to ask and answer again and again in order to understand how technology can be used to improve how students learn STEM disciplines (Hofer & Swan, 2008; Konold & Lehrer, 2008; Sfard, 2012). Focusing on the implementation of educational technologies, without questioning the reasons for *why* these technologies are being used and *what* pedagogical problems they are attempting to address, is doing a disservice to our teachers and students. This chapter, thus, emphasizes the importance of what we call a *deliberate technology-enhanced pedagogical practice* in STEM teacher education.

Now is the perfect time to re-examine STEM teachers’ engagement with technology, while considering how technology can help teachers to reunite the arts and the sciences, thus turning STEM into STEAM (Science, Technology, Engineering, Arts, and Mathematics) education. This examination is a 1000-mile journey and we begin it with a single step: an investigation of STEM teacher-candidates’ engagement with technology during their teacher education program. This engagement has a profound effect on forming their teaching philosophy, which will have a significant impact on their teaching careers. It is also very timely, as unlike their predecessors, most contemporary teacher-candidates are digital natives (Prensky, 2001a, 2001b): they were born into the “age of computers”. However, as we shall see below, being digital natives does not guarantee that teacher-candidates know how to use educational technologies to promote meaningful STEM learning (Milner-Bolotin, 2014a). We focus our discussion on exploring the following question:

> *Why* and *how* should educational technologies be incorporated into STEM teacher education in order to nurture the next generation of teachers capable of designing and implementing *deliberate technology-enhanced pedagogies* in their classrooms?

This is a big question that might have many answers. It is also complicated by the fact that digital technologies are “*protean* (usable in many different ways) (Papert, 1980), *unstable* (rapidly changing), and *opaque* (their inner-workings are hidden from users) (Turkle, 1995)” (Mishra & Koehler, 2007, p. 2215).

Therefore, we will unpack this big question through answering more specific sub-questions, such as:

1. *What* are the key goals of 21st century STEM education?
2. *Why* is educational technology a valuable tool to help address these goals?
3. *How* might STEM teacher-educators implement *deliberate technology-enhanced pedagogies* in order to engage teacher-candidates in meaningful learning?

To answer these questions we need to adopt a theoretical framework that will help us critically examine available research evidence. The Technological Pedagogical Content Knowledge (TPCK) framework will serve the theoretical lens for this chapter (Koehler & Mishra, 2009; Mishra & Koehler, 2007). It is discussed in detail in the following section.

Theoretical Framework: TPCK

STEM teacher education in the 21st century is even more important and challenging than it was a century ago. Computers and new technologies haven't replaced teachers, but they have profoundly affected the roles teachers play in our schools. Unlike the STEM teachers of the 20th century, modern teachers cannot continue assuming the role of authoritative dispensers of information, as their students have an unprecedented access to it. Moreover, as these digital savvy students are very different from the students we taught in the past (Levin & Arafeh, 2002) and as STEM standards are continuously evolving (National Research Council, 2013), 21st century teachers have to learn how to use rapidly evolving technologies to address the educational challenges of the new millennium (Crippen, Biesenger, & Ebert, 2010; Gerard, Varma, Corliss, & Lin, 2011; Harris & Hofer, 2011; Krajcik & Mun, 2014).

Therefore, it is the right time to break away from the educational technology pendulum mentality that swings educators back and forth between two pedagogical extremes: from the incurable technophilia (the "unconditional love" for all technological innovations without paying attention to their potential pedagogical impact) to the unyielding educational technophobia expressed through the unabating fear and skepticism towards novel educational technologies and their potential pedagogical impact (Cuban, 2001; Cuban, Kirkpatrick, & Peck, 2001; Kirkpatrick & Cuban, 1998; Krajcik & Mun, 2014). As Cuban warned educators more than two decades ago, if we do not carefully examine the pedagogical implications of computer-based instruction and how educational technologies can help address the issues of teaching and learning, we are bound to keep reforming our educational system again, again, and again with little significant results (Cuban, 1990).

Cuban's admonition resonates with the concerns expressed by Shulman in his seminal 1986 American Educational Research Association Presidential Address (Shulman, 1986). In his paper, he traced the knowledge growth in the teaching profession in the United States over the last century and emphasized that teacher-educators should focus on helping teacher-candidates develop their Pedagogical Content Knowledge (PCK) that comprises both the content knowledge (i.e. mathematics, science, art, history) and the knowledge of pedagogical approaches relevant to teaching the content and the practices of the subject to a particular group of students. Shulman called the lack of focus on PCK in teacher education programs the "missing paradigm" problem. He emphasized that teacher-educators should not limit themselves to discussing general context-free pedagogical practices (today we can compare it with discussing general context-free educational technologies), but should embed these pedagogical practices in a subject-specific context. In Shulman's own words:

> My colleagues and I refer to the absence of focus on subject matter among the various research paradigms for the study of teaching as the "missing paradigm" problem. The consequences of this missing paradigm are serious, both for policy and for research… Research programs that arose in response to the dominance of process-product work accepted its definition of the problem and continued to *treat teaching more or less generically or at least as if the content of instruction were relatively unimportant.* (Shulman, 1986, p. 6) (italics added)

Thus, PCK for teaching physics, mathematics, art or history will undoubtedly have common elements, yet there will also be many essential subject-specific aspects. Moreover, Shulman's address clearly highlighted the difference between the knowledge of the subject matter, Content Knowledge, (the fundamental content knowledge needed for future educators, researchers, engineers, etc.) and the knowledge of the content-driven pedagogies required to be able to teach this subject (PCK).

With the development of educational technologies, Shulman's PCK framework was expanded to include the technological component. The Technological Pedagogical Content Knowledge (TPCK) framework was proposed by Koehler and Mishra (2009) to emphasize the role of educational technologies in this process. Teachers should learn how specific educational technologies can be utilized in order to promote student understanding of both the subject content and its practices. Thus, the "T" (Technological) in TPCK refers to both the mastery of the technological tools and their pedagogical implications. According to this framework, in order to help teachers acquire TPCK, they have to actively engage in designing *authentic pedagogical tasks* that use educational technologies to serve specific pedagogical purposes. This active and deliberate engagement with technology should begin early in teachers' careers. In this chapter we argue that this process should start during the teacher education program in order to allow teacher-candidates to experience educational technologies both as learners and as future teachers (Milner-Bolotin, 2014a; Milner-Bolotin, Fisher, & MacDonald, 2013). In addition, educational technologies are tools that shape teacher-candidates' views and attitudes about teaching and learning (Milner-Bolotin, 2014a). This active pedagogically-driven engagement with educational technologies will support teacher-candidates in becoming active designers of pedagogically-driven technology-enhanced educational materials (Milner-Bolotin, 2014b).

In examining the process of engagement of STEM teacher-candidates with educational technologies, we will be guided by the techno-pragmatic approach suggested by Di Petta (2008) that focuses on technology serving specific pedagogical goals and by the TPCK framework discussed above.

Exploring STEM Teacher-Candidates' Engagement with Technology

This section explores STEM teacher-candidates' engagement with technology. We begin by identifying the key questions faced by modern STEM educators. Then we discuss how they can be addressed through pedagogically-driven use of educational technologies. We finish with the discussion of a possible model for technology-enhanced STEM teacher education and its pedagogical implications.

What are the Key Goals of 21st Century STEM Education?

STEM education has been profoundly affected by the rapid technological advances occurring in our society (Krajcik & Mun, 2014). For example, ubiquitous access to information and the availability of real life data collection tools deemphasize the importance of factual memorization, while placing a renewed emphasis on authentic problem solving and critical thinking (Eijck & Roth, 2009; Milner-Bolotin, 2012; Milner-Bolotin & Moll, 2008; Schwartz, Lederman, & Crawford, 2004). Ever increasing computing and visualization power of modern computers requires students to be able to model real life physical phenomena rather than solve highly simplified "plug-and-chug" problems (Finkelstein et al., 2005; Milner-Bolotin & Nashon, 2012). The availability of computer simulations has opened unprecedented opportunities for student-driven scientific investigations that were unimaginable before, thus requiring very different skills from the students (Perkins et al., 2006; Wieman, Adams, Loeblein, & Perkins, 2010). Lastly, the low level of scientific literacy and interest in STEM in the general population stresses the importance of improving student interest in and attitudes about STEM (Let's Talk Science, 2012, 2013; Wieman & Perkins, 2005).

These changes prompted many countries to reconsider their STEM education goals. For example, the Next Generation Science Framework (recently released U.S. Science Standards) expressed the desired science outcomes for the 21st century through five distinct STEM learning goals:

> The overarching goal of our framework for K-12 science education is to ensure that by the end of 12th grade, *all* students (1) have some appreciation of the beauty and wonder of science; (2) possess sufficient knowledge of science and engineering to engage in public discussions on related issues; (3) are careful consumers of scientific and technological information related to their everyday lives; (4) are able to continue to learn about science outside school; and (5) have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (Committee on a Conceptual Framework for New K-12 Science Education Standards, 2013, p. 14) (numbering added)

The five STEM education goals outlined above emphasize the importance of engaging students in inquiry-based authentic problem-solving which extends beyond the traditional classroom science. For example, modern art, architecture and design require deep STEM knowledge, while "the appreciation of the beauty of science" highlights the reciprocity of arts and sciences. Technology is viewed as a vehicle for exploration of science and mathematics ideas permeating the world we live in, a tool for engineering design, artistic expression, as well as a field of inquiry within itself.

> Engineering and technology are featured alongside the physical sciences, life sciences, and earth and space sciences for two critical reasons: to reflect the importance of understanding the human-built world and to recognize the value of better integrating the teaching and learning of science, engineering, and technology. (Committee on a Conceptual Framework for New K-12 Science Education Standards, 2013, p. 18)

The successful implementation of these Standards will require STEM teachers to reconsider the role of technology in their classrooms. This, in turn, will necessiatate teachers to acquire a STEM-specific TPCK. The following section uses three subject-specific examples to illustrate how educational technology can help address these 21st century STEM education goals.

How Can Technology Help Address 21st Century STEM Goals?

This section briefly outlines three examples of technology-enhanced pedagogies that help address the STEM education goals mentioned above. The first example illustrates the use of live acquisition systems to conduct authentic investigations. The second one focuses on the use of computer simulations and visualizations. The last example illustrates how electronic response systems (clickers) can be used to engage students in conceptual science learning in order to promote their critical thinking skills.

Using Data Acquisition Systems to Promote Authentic STEM Learning

In order to help students develop appreciation of STEM, it is important to engage them in authentic investigations that are rooted in everyday life phenomena (Eijck & Roth, 2009; Milner-Bolotin, 2012). This also helps students become critical consumers of STEM-related information. These inquiry activities rely on students' ability to collect and analyze real-life data using data acquisition systems, such as Logger Pro (Vernier-Technology, 2015). These data acquisition systems include various sensors (hardware) and software available for data analysis that allow synchronous or asynchronous data acquisition and analysis. In addition, sensor-driven data acquisition can be combined with video recording of the experiment to help students connect multiple representations of the same phenomenon, such as graphs, video recording, equations, etc. For example, data of a student jumping off a force plate can be collected in class, such as shown in Fig. 1. The students can then perform an analysis of this data, connecting theoretical knowledge (learning about Newton's laws) with practical applications and kinesthetic experiences (Milner-Bolotin, Kotlicki, & Rieger, 2007). Moreover, the students can video record experiments or everyday life phenomena outside of class, such as water coming out of a water hose, various moving objects, collisions, launch of a water rocket, etc. Then these files can be imported into video analysis software to conduct a frame-by-frame investigation (Antimirova & Milner-Bolotin, 2009). This is especially valuable as many scientific phenomena happen at very short time scales and slowing them down can reveal a lot of interesting and often hidden information. In addition, students can analyze video files posted by others on the internet, for example, short-lived phenomena, such as collisions and objects' deformations recorded with very expensive equipment (for example, a fast speed camera) that might not be available to the students (Brown, 2010).

Data acquisition systems can also be used to engage students in authentic inquiry-based learning that is akin to a scientific process through asking students to make

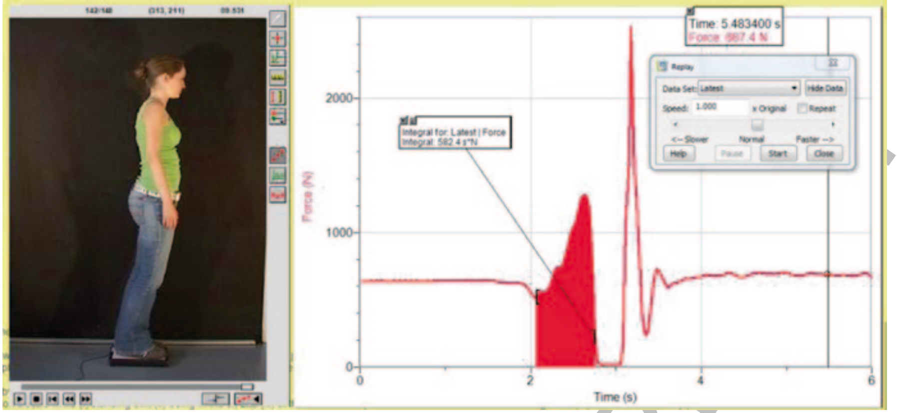


Fig. 1 An analysis of a student's jump off a scale performed using a Logger Pro data acquisition system. The student is standing on a digital scale that records the force exerted by the student (which is often incorrectly interpreted as student's weight) and sends it to a computer

predictions based on scientific concepts they studied earlier and then test these predictions in real time (Milner-Bolotin, 2012; Sokoloff & Thornton, 2004). This helps students to transform scientific facts into scientific ideas and explore their implications in classroom science and everyday life. This is crucial for helping students develop critical thinking capacities and become critical consumers of science-related information. Henri Poincare once said "Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house". To help students realize that the power of scientific ideas is their ability to predict the results of new experiments and new phenomena, the students have to have an opportunity to experience this first hand and not just to read about it in textbooks (Etkina et al., 2010).

Use of Computer Simulations and Modeling Software to Promote Scientific Mind Set and Critical Thinking Skills

While data collection and analysis are crucial components of authentic scientific inquiry, not every experiment can be performed under "real-life" conditions. And even if an experiment can be performed, the scientific mechanism behind it might be invisible "to the naked eye". For example, in recent years due to the Fukushima disaster there have been a lot of discussions about the effects of nuclear power plants and radiation in general on our lives. While the topic of radiation prominently featured in public debate, few laypeople possess scientific knowledge to be able to critically participate in such a discussion. Computer simulations, such as the PhET project (Wieman et al., 2010) is an example of a suite of STEM computer simulations built on solid educational research evidence (Figs. 2 and 3). These simulations help students not only to understand scientific concepts, such as radioactive decay shown in Fig. 2, but also conduct scientific investigations in these virtual

Fig. 2 PhET computer simulation "Alpha Decay"

environments. Since many of these simulations are free, they can be used by the students both in school and at home. Simulations can also help students understand the relationships between the sciences and the arts. For example, through exploring computer simulations of the natural phenomena such as radioactivity, light and sound, the students can understand the workings of musical instruments, and appreciate scientific contributions to the realms of arts, architecture, music, medicine, environment and everyday life (Figs. 2 and 3).

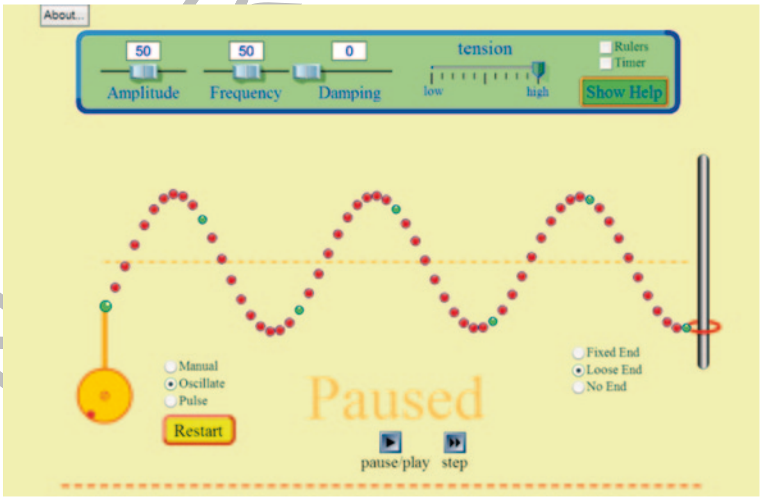


Fig. 3 PhET computer simulation "Waves on a string"

The investigations of the physical properties of waves (Fig. 3) and their applications to the design of musical instruments and the production of sound become especially meaningful when students, many of whom are interested in music, realize these connections (Jeans, 1968). Moreover, many famous scientists, such as Sir James H. Jeans mentioned above were also musicians and artists, making the modern distinction between the arts and the sciences a relatively recent phenomenon. Lastly, the recent symbiosis of the arts and the sciences in the realm of the digital arts, such as visual effects in film, television, and video game production, helps build bridges between the fields, producing very powerful STEAM education opportunities. It enriches students from both the arts and the sciences and opens new creative opportunities in both fields.

As a result of the proliferation of computer simulations, there has been a lot of interest in comparing student learning in virtual and real-life learning environments. Ample research indicates that learning in virtual environments has significant benefits for promoting student conceptual understanding (Finkelstein et al., 2005). Moreover, as indicated earlier, virtual learning environments have an additional benefit: students can test their ideas and receive immediate feedback to guide their investigation. This is not as easy to implement with real-life equipment. Lastly, it has to be noted that as with any technology, the pedagogical effect of computer simulations in STEM classrooms depends on teachers' abilities to implement them effectively in day-to-day instruction and align these activities with the final assessment.

Another prominent example of technology that empowers students to apply STEM to their lives through bridging the arts and the sciences, thus turning STEM into STEAM, is dynamic modeling software, such as GeoGebra (Hohenwarter, 2014) or Geometer's Sketchpad (Sinclair & Yurita, 2008). These dynamic mathematical software tools allow students to experience mathematical construction, the interdependencies between mathematical variables and visual (often very artistically beautiful) objects. Unlike traditional paper and pencil geometrical constructions, where a construction or a graphical representation cannot be changed or manipulated easily, GeoGebra allows students to develop a mathematical language, dynamically test their understanding, as well as visualize abstract mathematical relationships. GeoGebra is freely available to teachers and students, and the GeoGebra educational community is a powerful community-created pedagogical resource (Fenyvesi, Budinski, & Lavicza, 2014; Hohenwarter, Hohenwarter, & Lavicza, 2008). Dynamic mathematical software opens doors to using mathematical modeling in order to explore the relationships between art (e.g. paintings, patterns, architecture, textile, and mosaics) and mathematics. The dynamic features of GeoGebra or Geometer's Sketchpad allow students to manipulate geometrical shapes, visualize abstract mathematical concepts and search for mathematical patterns and relationships behind everyday life phenomena, artistic artifacts, or natural phenomena. For example, students can use GeoGebra to explore regular and semi-regular tessellations, mosaics and geometrical patterns, and their use in art and architecture (many of these activities can be found on GeoGebraTube—www.geogebratube.org) (Fig. 4).

One of the most striking modern examples of the deep interconnections of all elements of STEAM fields is the use of art "powered" by mathematics and science in modern movies and animation films. Recently Tony DeRose—a computer

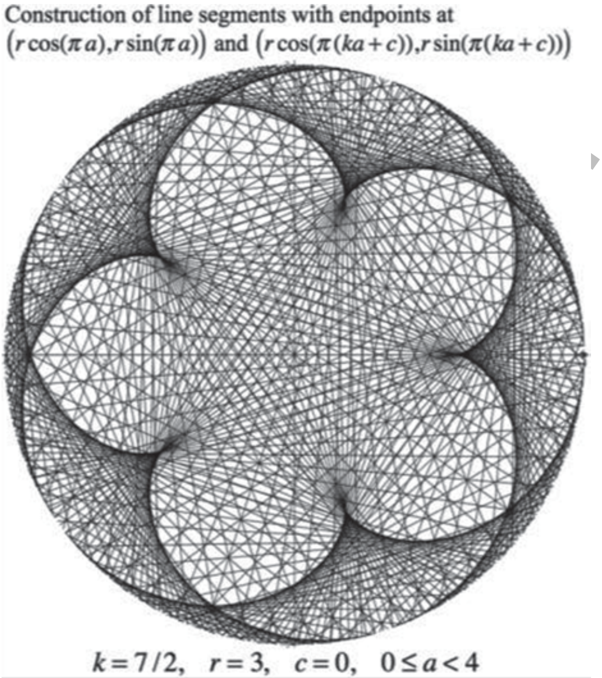


Fig. 4 An example of a construction of a cycloid bounded by tangent lines using GeoGebra software (http://www.talljerome.com/mathnerd.html)

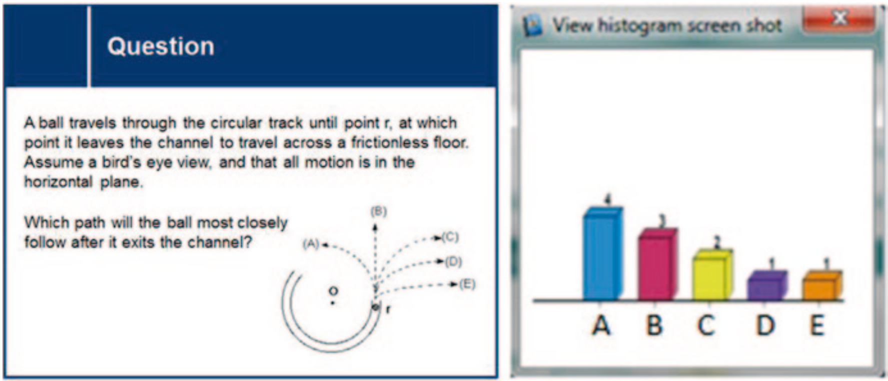
scientist working with artists and animators at Pixar Animation Studios—presented an invited talk "Math in Movies" at the Mathematics Association of America Distinguished Lecture Series. In this talk he noted:

> There is indeed a lot of mathematics behind the scenes… In each of these animated films, constructed entirely on computers, trigonometry helps rotate and move characters, algebra creates the special effects that make images shine and sparkle, and integral calculus helps light the scenes. (http://www.maa.org/news/interview-tony-derose, October 15, 2009)

These are only few examples of powerful interconnections of STEAM disciplines and the growing opportunities for productive and creative collaborations of artists, scientists and mathematicians. In order to help students to see these opportunities we have to educate a new generation of STEAM teachers who are ready to use technology in order to engage their students in meaningful learning.

Use of Electronic Response Systems to Promote Active Student Engagement and Meaningful Learning

In order to help students relate STEM disciplines to their lives and build the knowledge that they can use outside of school, students have to be actively engaged not only during labs and hands-on activities, but also during "traditional" lessons (Hake, 1998).



Question

A ball travels through the circular track until point r, at which point it leaves the channel to travel across a frictionless floor. Assume a bird's eye view, and that all motion is in the horizontal plane.

Which path will the ball most closely follow after it exits the channel?

Fig. 5 An example of a conceptual multiple-choice question and the distribution of students' responses. The correct answer B was chosen by 3 out of 11 students

One of the most common active engagement pedagogies in postsecondary STEM classrooms is Peer Instruction (PI) (Lasry, Mazur, & Watkins, 2008; Mazur, 1997). It utilizes Classroom Response Systems (clickers) to engage students in interactive activities and discussions through conceptual multiple-choice questions that target student difficulties, often referred to as misconceptions (Milner-Bolotin et al., 2013) (Fig. 5).

PI has been found to be very effective in college STEM classrooms when students used either clickers (Hake, 1998; Milner-Bolotin, Antimirova, & Petrov, 2010) or flashcards (Lasry, 2008). However, due to its cost (each student has to have a clicker to take part in the voting), PI has not been widely used in K-12 classrooms. With the advent of new cost-effective models for its implementations (such as using smartphones or tablets instead of clickers), it is becoming more popular in secondary schools. We have written about the implementation of this pedagogy (Kalman, Milner-Bolotin, & Antimirova, 2010; Milner-Bolotin, 2004; Milner-Bolotin et al., 2013). There is extensive research evidence that the success of PI or any other clicker-enhanced pedagogy is not in the technology itself, but in the pedagogical skills of the teachers and in the quality of the available resources (Milner-Bolotin et al., 2013). These findings highlight the importance of developing teacher-candidates' TPCK during teacher education programs, so teachers will be ready to utilize this technology when it becomes available in their classrooms (Milner-Bolotin, 2014b).

How Should STEM Teacher-Educators Implement Technology-Enhanced Learning Environments: Exploring Possible Models for Technology-Enhanced STEM Teacher Education

While it is impossible to prepare teacher-candidates for all the technological innovations that are to emerge during their careers, they should begin the acquisition of their TPCK as soon as they enter the teacher education program (Milner-Bolotin et al., 2013). Teacher-candidates should be engaged in thinking about technology as a vehicle to help promote STEM educational goals. Therefore, the main argument of this chapter is that in order to prepare STEM teacher-candidates for a successful teaching career in the 21st century, they have to experience multiple support mechanisms during their teacher education program. In particular, science methods courses have to support teacher-candidates in:

a. Learning how to utilize educational technologies as enablers of big pedagogical ideas;
b. Experiencing active technology-enhanced engagement as learners and as teachers;
c. Adopting pedagogical values congruent with this technology-enhanced active engagement;
d. Designing and implementing technology-enhanced educational materials that serve clear pedagogical purposes.

The following section will expand on what we mean by the four-way support structure through a study situated in the context of physics teacher education at a large research university in Western Canada. The study took place during a semester-long physics methods course and a 13-week school practicum that followed. The goal of the study was to explore how educational technologies can be used to help STEM teacher-candidates acquire subject-specific TPCK and to translate this knowledge into active engagement pedagogical practices during the consequent school practicum and hopefully during their future STEM teaching.

Developing Teacher-Candidates' TPCK Through Modeling Peer Instruction in a Physics Methods Course

As discussed earlier, while Peer Instruction (PI) is very common in large undergraduate courses, it is still rare in K-12 classrooms. It is also seldom found in STEM methods courses. One of the commonly cited reasons for not using this technology in teacher education is the cost of the system and the reluctance of schools to spend money on it. Yet, with the developments of smartphone technologies and the Bring-Your-Own-Device "revolution" in K-12 schools, it is becoming apparent that this technology will soon penetrate the school walls. Two questions remain: (1) Will the teachers with the access to this technology have the TPCK necessary to draw pedagogical benefits from PI and question-driven pedagogy? and (2) What can teacher educators do in order to assure that PI will not become another example of a technological fad that will fade away as soon as it came? Our response to these questions is preparing teacher-candidates through incorporating PI into the physics methods course. We described how we have done it in detail elsewhere (Milner-Bolotin et al., 2013). We briefly outline the study below.

The study was conducted in a Physics Methods course in the Teacher Education Program at a large research university in Western Canada during the 2012–2013 academic year. The course lasted for one term (39 h in total) and included 13 physics teacher-candidates. It took place in a flexible laboratory environment so that different modes of student engagement were able to be implemented during the same class period. PI pedagogy was modeled during every class meeting.

In order to help teacher-candidates see the big pedagogical ideas behind PI and learn how clicker-enhanced pedagogy should be implemented, the course began with a discussion of the importance of active student engagement and how PI helps promote it in a physics teaching context. Research evidence was brought and discussed during the class (Hake, 1998). Then the instructor focused on student conceptual learning and the development of pedagogically effective conceptual questions (Beatty, Gerace, Leonard, & Dufresne, 2006). At the same time, different conceptual multiple-choice questions were modeled and teacher-candidates were invited to participate in PI pedagogy first as students and consequently as teachers. This dual experience of technology-enhanced pedagogy by teacher-candidates (both as students and as future teachers) was central to the course philosophy. Teacher-candidates were also encouraged to use a special resource of STEM conceptual questions designed by our research team that modeled effective conceptual questions (Milner-Bolotin, 2015). This provided pedagogical support and scaffolding required for mastering the necessary TPCK. This brought up many discussions about the value of powerful distractors (incorrect choices in a multiple-choice question) and the ability to test different scientific hypotheses with the students. It also opened doors to the discussion about how various technologies were utilized in order to support active student engagement, conceptual learning, and building bridges between science as experienced in class and as experienced in everyday life. This helped teacher-candidates not only to experience this technology-enhanced pedagogy, but also to slowly uncover and adopt the pedagogical values associated with its pedagogically effective use.

As teacher-candidates' TPCK strengthened, they were asked to start working on designing their own conceptual questions (every teacher-candidate was required to submit five conceptual multiple-choice questions). These questions had to include clear pedagogical purposes and detailed explanations of the distractors. The course instructor and a Teaching Assistant provided detailed formative feedback on these questions. In addition, the questions were shared between the group members so that teacher-candidates had an opportunity to comment on them and exchange ideas. During the following year, the PeerWise system (Denny, 2014) was used to promote effective sharing and collaboration of conceptual multiple-choice questions designed by teacher-candidates (Milner-Bolotin, 2014b). PeerWise is an online collaborative database that allows students to upload their multiple-choice questions (including solutions), respond to the questions designed by their peers, rate these questions, provide comments, and respond to the comments provided by their peers and the course instructor.

This methods course was followed by a 10-week school practicum where teacher-candidates were able to teach physics lessons and implement the pedagogy of their choice, including PI, in practice. During their school practicum teacher-candidates were observed by their school and university advisors, as well as by the physics methods course instructor.

In the following section, we will briefly outline the results of the research study that investigated the effects of this pedagogy on teacher-candidates' TPCK, their attitudes about active engagement, and their views on the nature of science and of science education.

The Effects of PI Modeling on Teacher-Candidates' TPCK and Their Attitudes About Science Teaching and Learning

In order to investigate the effects of modeling PI pedagogy on teacher-candidates' TPCK and their attitudes about science teaching and learning we collected and analyzed conceptual questions contributed by the teacher-candidates. We also conducted multiple individual interviews with teacher-candidates and a focus group during the year and observed their teaching during the practicum that followed the course. In addition, we collected teacher-candidates' reflections and observed their behavior during class. We described this analysis in detail elsewhere (Milner-Bolotin et al., 2013). Here we would like to outline a few of the most important findings.

1. Teacher-candidates acquired PCK necessary for designing pedagogically effective conceptual multiple-choice questions. The questions submitted at the end of the course were rated using Bloom's Taxonomy of Educational objectives (1956). Their average cognitive level corresponded to the application level on Bloom's taxonomy. Most of the questions targeted specific conceptual difficulties, were scientifically accurate, and had meaningful distractors that were justified by the teacher-candidates.
2. Teacher-candidates used technology, such as computer simulations and data acquisition systems to design inquiry-driven questions that integrated experimental and theoretical knowledge and skills in order to achieve specific pedagogical goals. This required them to possess significant TPCK.
3. Teacher-candidates modeled different ways of PI implementation during the methods course. A number of them also implemented PI during the practicum using clickers, smartphones, or flashcards. This illustrates that they were able to transfer the TPCK they acquired in the methods course to their practicum.
4. The interviews and focus group discussion indicated that teacher-candidates' active engagement during their physics methods course had a significant positive effect on their teaching philosophy and their views on the importance of student engagement in science. Teacher-candidates not only learned about new educational technologies, but also began seeing technology as a powerful tool to promote deeper conceptual understanding and meaningful science learning.

We will finish this section with a few quotes from the teacher-candidates. These teacher-candidates discussed how clicker-enhanced pedagogy can become a mechanism for promoting active student engagement and conceptual science learning. These quotes shed light on the emergence of teacher-candidates' TPCK and their views about the role of technology in STEM education:

> It wasn't just the clickers alone. It was also in…. the presentation of the question. It wasn't a simple plug in the answer-type question. It had to be conceptual, in which you could promote …, the Bloom's taxonomy, the higher learning of students. So, in itself, clickers… is only a tool. But it needs to be complemented with good conceptual questions in order to make it work (Teacher-candidate E).

> … Some of the physics 11 s who are just doing it to do a science, and are just, 'Alright, Physics, I'll try it out.' Some of them were not as engaged, and I think doing the… voting-style questions helped get them more into it and more involved. So I'd say… it's helpful to get those students who hide at the back in these 30 person classes (Teacher-candidate C).

The third quote sheds light on the teacher-candidates' views on the nature of science and their science teaching philosophy:

> … physics is…not about applying formulas, and doing math. It is…about gaining an appreciation of the world around us. And, being able to use your understanding and extrapolate … explain what's happening around you… (Teacher-candidate A).

These quotes highlight the importance of active pedagogical engagement of STEM teacher-candidates in their methods courses and the role of technology in this process. As we described in the beginning of this section, in order to promote meaningful teacher-candidates' engagement with technology, teacher educators should model it in the classroom, allow teacher-candidates to experience the effects of technology-enhanced pedagogies on their own learning, support them in adopting the philosophical values congruent with the use of this technology, and provide teacher-candidates with safe opportunities to practice the implementation of these technology-enhanced pedagogies into practice.

While this physics methods course used technology extensively, teacher-candidates realized that technology was a vehicle for promoting active engagement and not the purpose within itself. This pedagogically-driven technology-enhanced engagement had a positive impact on their teaching philosophy and views on the nature of science teaching. This brings us back to the techno-pragmatic approach suggested by Di Petta (2008), as the success of technology-enhanced pedagogy should be judged not by the extent of the technology use, but by the impact of technology that was used in achieving clear pedagogical goals.

Conclusions and Future Directions

This chapter examined the 21st century pedagogical goals that can be addressed through STEM teacher-candidates' engagement with technology. It also discussed the possibilities of using modern technologies in order to bring the "A" into STEAM education, such as computer simulations, dynamic mathematical software, and virtual learning environments. We outlined *why* active technology engagement should become an important part of teacher education programs and *how* technology can be incorporated into STEM methods courses. We also discussed how modern educational technologies can help build bridges between the arts and the sciences, thus engaging teacher-candidates and consequently students involved in STEAM education at a more meaningful level. This active engagement should become the first step in helping teacher-candidates build solid TPCK and positive attitudes about educational technologies. More importantly, technology can provide opportunities for interdisciplinary projects, where students and teachers with different interests, skills and backgrounds can collaborate to create meaningful artefacts, exploring architectural designs, tessellations, the occurrence of special mathematical curves and shapes in art and nature, fractals, animation, visual effects, etc. We focused on three types of educational technologies pertinent to STEM (and possibly STEAM): data acquisition systems, computer simulations and dynamic visualization software, and electronic response systems. We provided examples of how they were used in a physics methods course for secondary physics teachers. We also discussed the effects of these technologies on teacher-candidates' TPCK, their teaching philosophies, and their views on the nature of STEAM teaching.

The main conclusion of this chapter is that in order to help STEAM teachers develop positive attitudes about educational technologies, they have to have an opportunity to start building their TPCK during their formative teacher education years. Teacher-candidates should also have ample opportunities to experience these technologies both as students and as future teachers. STEAM methods courses in teacher education programs are perfect opportunities for teacher-candidates to acquire these experiences in a safe and supportive environment. Moreover, STEAM education research on the effective use of educational technologies should become a theoretical base for these methods courses. Teacher-candidates should also be encouraged to read these papers and incorporate their results in their lesson planning. This will build much needed and often missing bridges between the results of STEAM education research and STEAM education practice.

Technology has the potential to become a very powerful educational tool, yet in order to benefit from it teachers have to be continuously supported in the development of their TPCK. It is not surprising that technology will be as effective as the TPCK of the teachers who are implementing it. We strongly believe that figuring out effective ways of providing this support to teacher-candidates, as well as to practicing teachers will become the focus of extensive STEAM education research in the coming decades.

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