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ADAPTABLE LEARNING THEORY FRAMEWORK FOR TECHNOLOGY ENHANCED LEARNING

INTRODUCTION

In an increasingly connected technological world, theoretical approaches to education and the tools used to educate are continually changing. Learners expect to use technology in education (Sandars, 2012). The use of technology, however, "should not occur without thinking about how people learn best" (Jackson, Gaudet, McDaniel, & Bramer, 2009, p. 71). The sheer volume of technological innovations with educational potential along with the myriad of instructional theories and models present quite the challenge for educators. It can be daunting and confusing to align theories, technologies, content, learner characteristics, instructional strategies, and goals to effectively and efficiently bring about desirable learning outcomes. Reference to technology simply as a tool "denies the professional responsibility to use available tools both effectively and efficiently" (Anderson & Dron, 2012, para. 4).

Linking pedagogy and technology for information and communication technologies (ICT) in education, Richards (2006) writes "…too often in practice the actual use of ICTs reflects the very 'transmission' and 'reproduction' paradigms of teacher-centered face-to-face learning challenged by the new theories of pedagogy which emphasize the learner-centered implications of new learning technologies" (p. 240). Richards indicated three convergent principles of design and development for linking pedagogy and technology: "the organization of information, the facility for communication, and some convergent mode of user interaction" (p. 244).

A contemporary framework is needed to connect these components with learning theory and to ultimately serve as a guide to educators grappling with how to align the interrelated components of effective instruction when using educational technologies. The objective of this chapter is to present a viable contemporary framework to fulfill this need. The Adaptable Learning Theory Framework for Technology Enhanced Learning (AF-TEL) provides a framework based on the cognitive presence, social presence, and teaching presence tenets of the Community of Inquiry model (Garrison, Anderson, & Archer, 2003) to achieve desired educational outcomes.

BACKGROUND

Behaviorism, cognitivism, and constructivism are three predominant learning theories that have guided education and instructional development. Effective and applicable instructional theories and instructional strategies based on these learning theories are necessary with the advent of the Internet, social media, distance learning, open source learning, cloud storage, multimedia, artificial intelligence, virtual reality, video conferencing, 3D printing, robotics, and wearable computers. While education needs to build upon and integrate past influential theories, reformed instruction must also embrace theories and models of the digital age, an age characterized by connectivity, collaboration, short knowledge half-life, anytime access to stored information, rapidly emerging technologies, and the need for higher order competencies for interpreting, synthesizing, and creating (Al-Khatib, 2009; Frank, 2005; Jackson et al., 2009; Sharkey, 2013; Siemens, 2004).

Maximizing the potentials of technologies for sustainable approaches to education is also a vital concern in this digital age. This contrasts with using technologies in one-time-only competitive events (Lye, Wong, & Chiou, 2013). In robotics for example, there is a progression from using robotics to teach building robots for a specific competition to perform a specific task, to using robotics for instructional purposes over a sustained period of time. The latter uses human-robot interaction to teach STEM (Science, Technology, Engineering, and Mathematics) topics as well as to help students improve collaboration and communication skills.

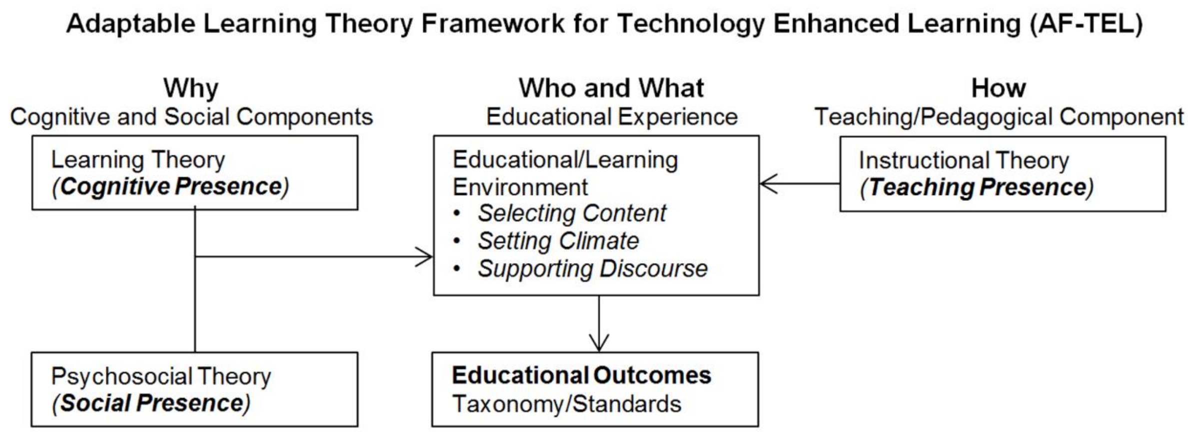
Robotic Interactive Learning Environment (RILE) is one curriculum that exhibits the use of technology as a sustainable approach to education. Robotics, web-based learning tools, and modern teaching approaches are integrated within RILE for teaching STEM topics to middle and high school students while fostering cognitive, communication, teamwork, and creative skills ("What is RILE", 2013). In regard to the high cost of equipment needed per student, RILE uses tele-robotics to allow students to remotely manipulate and control robots through a web-based interface. The central RILE laboratory is housed at University of West Florida (UWF). The RILE team is composed of innovators, academics, entrepreneurs, and physicists. Multiple field studies have been conducted with middle and high school students. Students in India, over 8,000 miles away, have been able to conduct physics experiments with the robots housed in the UWF lab. This study along with the other field studies have consistently demonstrated working with robots keeps students engaged and motivated in learning difficult STEM concepts (Prayaga, et al., 2012). Pondering the success of RILE sparked the desire to develop an adaptable learning theory framework for infusing technologies into educational experiences. Thus, RILE ignited the development of AF-TEL and RILE will be used to demonstrate AF-TEL for the purpose of this chapter. While RILE will be used as an example, AF-TEL may be used for a very broad range of technology enhanced learning experiences.

COMPONENTS OF THE FRAMEWORK

AF-TEL directs attention to the who, what, why, and how of learning. The key word in AF-TEL is *adaptable*. This framework may be modified to fit other settings with different learners, content, and educational technologies. Drawing upon the Community of Inquiry model, each component is aligned with a theory based on the demographics of the audience (Garrison, Anderson, & Archer, 2003). The learning, psychosocial, and instructional theories associated with cognitive, social, and teaching presence serve to establish the nature of the activities that take place in the learning environment. The general AF-TEL diagram is shown in Figure 1.

Figure 1. General diagram of the adaptable learning theory framework for technology enhanced learning

Insert Figure 1 about here



The Audience and Purpose (Who and What)

Audience

An obvious starting point for designing technology enhanced learning experiences is to clarify the setting, determine the role of the instructor or facilitator, and identify the skills and learning needs of the students. This is the *who* component of AF-TEL. The setting for instruction, whether it is face-to-face, a hybrid course, or an online course, must be clarified and aspects of the setting maximized for learning. The role of the instructor needs to be established. In most constructivist, learner-centered environments, the instructor takes on the role of an expert guide and coach who helps learners use the content, tools, creations, and collaborations to create knowledge. It is highly important to assess the learners' ages, and their existing cognitive skills, group collaboration skills, and technology skills. Attention to group size and gender balance in groups is also needed for optimal learning. For example, Ucgul and Cagiltay (2014) recommended for educational robotics programs, the number of students in a group must be balanced with the materials. Ucgul and Cagilty cited Edmiston's (2004) recommendation for each student in the group to have an assigned role at all times. Regarding gender balance, the Ucgul and Cagiltay study with elementary school students demonstrated mixed gender groups encourage social interactions and increase productivity. This study also supports implementing competition between groups through challenges to enhance engagement and motivation.

Educational Experience

The next step in designing technology enhanced learning experiences is to determine the content and the technologies. This is the *what* component of AF-TEL. Content is at the heart of the educational experience. When combined with the *how* component of AF-TEL, learners are able to achieve desired learning outcomes. Regarding technology selection, Sharkey (2013) highlights the importance of considering the rationale for using particular technologies and identifying the activities and interactions the technologies can support; if not used effectively, technologies may be counterproductive to learning. Sharkey adds, "sound pedagogical practices and teaching methods should never be compromised to incorporate technology into the classroom" (p. 35). Technology integration clearly requires skillful integration of all components of an educational experience (Sandars, 2012).

Consider for example, the *who* and *what* of RILE. Physics content is presented through an online curriculum which is divided into modules and then chapters by grade level (6th through 12th grades). The setting is middle and high school classrooms along with remote access from those classrooms to the RILE robots, housed in a central laboratory. For this particular example, the students are boys and girls in 8th grade, approximately 14 years of age, in a middle school. Teachers who use RILE have control over the entire curriculum and may use it as a teaching aid with their own curriculum. Another option is to use the entire RILE curriculum. Teachers grant student access to content and activities as desired. The learning tools and educational technologies are the e-learning curriculum, reading activities, video lectures, simulations and demonstrations, homework assignments, classroom activities, and tele-robotic activities. Students work in groups of three to four, stationed around each computer and perform physics experiments with the tele-robots in the central laboratory (Prayaga, et al., 2012; "What is RILE," 2013).

Educational Outcomes

Alignment of the educational experience with desired learning outcomes is emphasized in AF-TEL. Desired educational outcomes may be curriculum based, or based on a particular learning taxonomy such as Bloom's taxonomy (1956; Anderson & Krathwohl, 2001) or Gagné's taxonomy (1985). Taxonomies serve as a means to classify outcomes based on a learning hierarchy (Gagné, 1985). Educational outcome alignment to state standards is critical for many K-12 institutions in the United States. Twenty-first century skills alignment is possible as well. Rather than consider these outcomes individually, determining the desired educational outcomes early in the process through the application of AF-TEL ensures required standards are met in addition to key skills for the future. A focus on 21st century knowledge and skills continues to be a focus in the United States and other countries (Pearlman, 2010). Sharkey (2013) indicates, "When determining how to encourage the development of the key twenty-first century competencies, all aspects of teaching and learning should incorporate the components of active learning, critical thinking, and reflection" (p. 35).

Cognitive and Social Components (Why)

After educators define the content, learners, technology, and setting, attention is then given to the *why* of AF-TEL, the underlying cognitive and psychosocial theories. "Learners are influenced by innumerable psychological, social, and situational factors" (Jackson et al., 2009, p. 75). Learning strategies based on theories that align well with and even exploit learners' cognitive and psychosocial levels of development, will enhance motivation and achievement of learning outcomes. RILE works well in part because it capitalizes upon learners' stages of cognitive and psychosocial development. The theoretical works of Piaget and Erickson, working in harmony, are the components of AF-TEL that explain why RILE is effective regarding this age group of learners.

Piaget's Stage Theory of Cognitive Development

Psychologist Jean Piaget (1955) defined four stages of intellectual development. Through mental processes of balancing assimilation and accommodation, humans progress from sensorimotor intelligence, birth to two; to pre-operational thought, two to seven; to concrete-operations, seven to eleven; and, formal-operations, adolescent to adult. According to Bruner (1997), Piaget argues that mind is "an organized group of logical operations that mediate between the world…and our knowledge of that world" (p. 65). Piaget's cognitive theory focuses on the "direction of growth" rather than "the causes of growth" (p. 66). Bruner also indicated Piaget describes knowledge as being "made, not found" (p. 66). Accordingly, Piaget's theory is a constructivist theory as knowledge in the mind is constructed by interaction with the world, people, and things (Ackermann, 2001; Berland, Baker, & Blikstein, 2014). A learner's stage of cognitive development may be connected to the cognitive presence component of Community of Inquiry Model (Garrison et al., 2003). Cognitive presence is the "extent to which learners are able to construct and confirm meaning through sustained reflection and discourse in a critical community of inquiry" (Garrison et al., 2003, p. 115).

In keeping with the RILE example with 8th graders, by 14 years of age students have intellectually acquired concrete operations in thinking. By this age, teens are able to manipulate fixed objects while understanding objects may remain the same and change, at the same time. Teens are able to focus on more than one aspect of a situation or object and integrate more than one dimension. By entrance into the highest stage of cognitive development, formal-operations, teens are capable of using complex and abstract reasoning. At this stage of development, students are able to deal with symbolic thoughts, complex moral decisions, and the scientific process of forming hypotheses (McMahon & McMahon, 1986; Piaget, 1955). Intellectually then, 8th graders are cognitively ready and eager to work with the multi-faceted components of RILE.

Erikson's Stage Theory of Psychosocial Development

By early adolescence, the intellectual ability to reason abstractly works in tandem with intrinsic psychosocial processes, moving learners toward competence and identity formation. In short, the egos of learners in this stage of life require outlets for demonstrating their cognitive prowess. In a chapter entitled Eight Ages of Man in his book Childhood and Society, Erik Erikson (1950) discusses psychosocial stages of development that encompass the lifespan. Erikson diagrams these stages in an epigenetic chart and explains that in each stage, humans experience critical turning points. There is a sequence in development, with "variations in tempo and intensity" (p. 271). Ego virtues that provide the basis for success, happiness, and fulfillment develop out of successful resolution of each stage (Erikson, 1950; Good & Adams, 2008). The psychosocial strengths developed in each stage are systematically related to the strengths developed in all other stages and are dependent upon "proper development in the proper sequence" (p. 271). Erikson notes each critical item of psychosocial strength "exists in some form before its critical time normally arrives" (p. 271). According to Erikson, 14-year-olds who have successfully completed prior stages, have already developed virtues of drive and hope from the trust vs. mistrust stage; self-control and willpower from the autonomy vs. shame and doubt stage; and, direction and purpose from the initiative vs. guilt stage. At age 14, some students are in the midst of the industry vs. inferiority stage while others may have resolved this task and have moved on to the identity vs. role confusion stage. It is reasonable to ascertain that part of the success of RILE is that it exploits the intrapsychic psychosocial developmental processes of these two periods.

In the industry vs. inferiority stage, Erickson (1950) indicates learners are winning recognition by using tools to produce things. At this stage, learners devote "steady attention and persevering diligence" (p. 259) to the pleasure of work completion in order to stave off a sense of inadequacy or inferiority. Also during this period, the "technological ethos of a culture" (p. 260) develops. Erickson notes the importance of this stage for understanding society's roles in its technology and economy. Failure to use tools to develop competence at this stage will lead to a sense of being "doomed to mediocrity or inadequacy" (p. 260) and may even lead to becoming a "thoughtless slave of technology" (p. 261). RILE permits students to individually and collaboratively interact with modern technological tools such as the Internet, programming software, and tele-robotics to encourage the development of competence in physics knowledge. This clearly aligns with the virtue of competence that develops out of successful resolution of Erikson's industry vs. inferiority stage.

Erikson describes the ending of childhood and the beginning of youth in the identity vs. role confusion stage: "The growing and developing youths, faced with this physiological revolution within them, and with tangible adult tasks ahead of them are now primarily concerned with what they appear to be in the eyes of others as compared with what they feel they are" (p. 261). On the path to developing identity, youth are clannish and may temporarily over-identify "with the heroes of cliques and crowds" (p. 261). Erickson notes that clique-forming actually temporarily helps youth through the discomfort of identity confusion.

Identity formation occurs within social contexts (Erikson, 1968). School social environments "that are warm, supportive, and encouraging of adolescent independence are thought to be conducive to the successful resolution of the identity crisis stage" (Good & Adams, 2008, p. 221). Fidelity is the virtue produced by the identity vs. role confusion stage. "Fidelity produces loyalty and commitment to chosen ideologies, as well as the ability to maintain loyalty over time to those commitments" (Good & Adams, p. 226). Another reason for the success of RILE, therefore, is it exploits the intrapsychic need of students who are working on developing a sense of uniqueness while simultaneously developing a sense of sameness (Hamman & Hendricks, 2005). Working in groups with other teens to carry out physics-related tasks using modern technologies, fits well with this developmental stage. Group collaboration offers students the opportunity to identify with and explore the ideologies of other teens while embracing their own uniqueness.

Basing the educational experience upon the psychosocial stage of learners is useful for enhancing the social presence component of a Community of Inquiry. Social presence is defined by Garrison et al. (2003) as "the ability of learners to project themselves…socially and emotionally…as real people…" (p. 115). Watson (2007) discusses the social interaction as a key to learning and encourages universities to design buildings and "inherently conversational" spaces to enhance collaboration and reflection. Even online learning environments can heed this directive and create safe and inviting spaces for social interactivity.

Teaching/Pedagogical Component (How)

In planning a technology enhanced learning experience an instructor may ask, "What instructional theory will align well with the content, the technologies, and the cognitive and social stages of the learners to best guide specific learning strategies for helping learners achieve desired learning goals?" This is the *how* component of AF-TEL; this component is clearly interrelated to the *who*, *what*, and *why* of educational experiences. Even though the basic role of the instructor is identified in the *who* element of AF-TEL, it is here, in the *how* component, that the teacher's specific roles are defined. The *how* may be viewed through teaching presence, the structure and process component, of Community of Inquiry Model. Anderson, Rourke, Garrison, and Archer (2001) define teaching presence "as the design, facilitation, and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile outcomes" (p. 5). Anderson et al. further explain it is only through active intervention of a teacher that a powerful technology becomes a useful instructional and learning resource. Constructionism offers an excellent theoretical framework for the teaching presence piece of technology enhanced educational experiences.

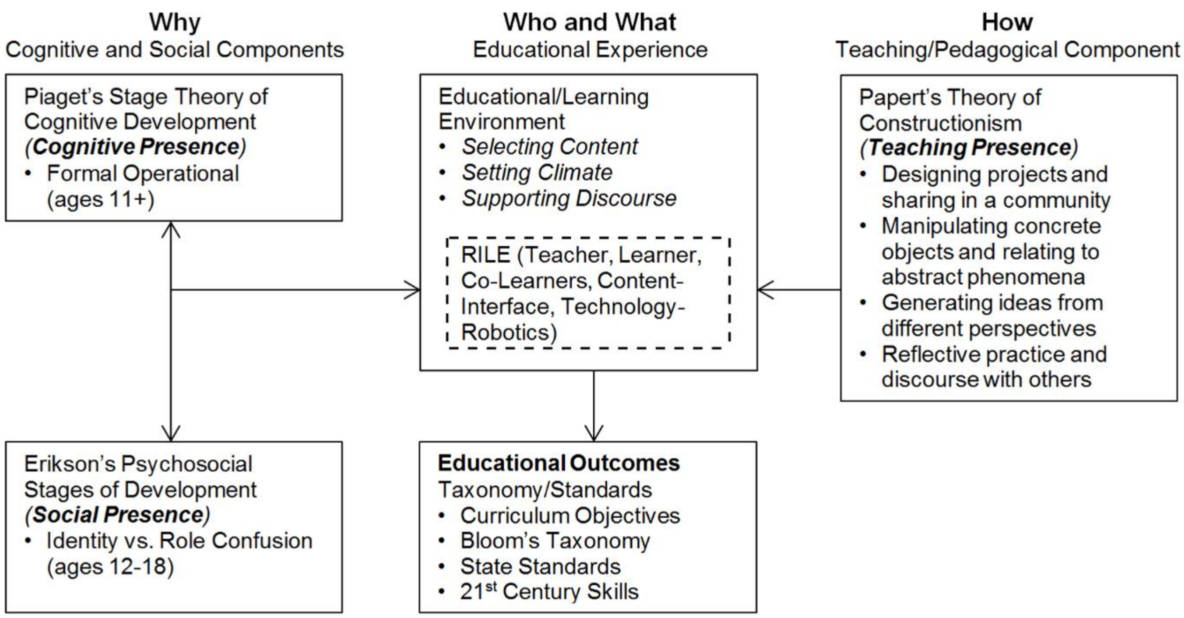
Papert's Theory of Constructionism

Berland et al. (2014) refer to Papert's constructionism as a popular and well-developed, project-based, student-centered approach to education. This main tenet of constructionism is learners build knowledge structures through progressive internalization of actions, particularly through constructing public artifacts. This is "learning by making" (Papert, 1991, para. 1). Papert emphasized a cyclical, iterative process in which feelings and ideas are projected into creating tangible objects to think with (Ackermann, 2011). These created artifacts in turn sharpen the learners' ideas and enhance communications with others. Building artifacts allows students to learn "complex content in connected, meaningful ways" (Berland et al., 2014, p. 206). Constructionism is highly useful in the digital age as it focuses on creating artifacts with digital media and computer-based technologies. Regarding RILE, a key factor in the success of this educational tele-robotics program, is it's grounding in the *how* of constructionism. Constructionism explains *how* RILE works. Building on the knowledge gleaned through the RILE eLearning content, students direct tele-robots to perform specific physics-related tasks. Students deepen their understanding of physics concepts by successfully making robots respond to their programming commands. All the components of AF-TEL aligned with RILE for 8th grade students, approximately 14 years of age, are demonstrated in Figure 2.

Figure 2. Diagram of the adaptable learning theory framework for technology enhanced learning applied to 8th grade students, approximately 14 years of age, in the Robotics Interactive Learning Environment (RILE)

Insert Figure 2 about here

Adaptable Learning Theory Framework for Technology Enhanced Learning (AF-TEL)



Several additional educational robotics examples are explored to address the usefulness of constructionism for blending pedagogy and technology with different learner profiles in different settings. Bers, Ponte, Juelich, Viera, and Schenker (2002) demonstrate a constructionist approach to integrating robotics in early childhood education. These authors clarify four basic tenets of constructionism: (a) learning occurs by designing meaningful objects and sharing them in a community; (b) manipulation of objects helps concrete thinking about abstract phenomena; (c) powerful ideas come from different realms of knowledge; and (d) self-reflective practice and discourse with others is crucial. Their study demonstrates that even in the early childhood years students are capable of developing technological fluency using laptops, digital cameras, and minidisk recorders to build and program robotic dinosaurs. Students used and honed communication and collaboration skills while exploring introductory engineering concepts. "Most importantly they developed self-esteem and confidence in themselves as learners" (p. 142). This latter outcome pinpoints the interrelatedness of the *what*, *how,* and *why* of AF-TEL. The students build on the content (the *what*) to create a robotic dinosaur artifact (the *how*). This capitalizes upon the *why* component: the learners' concrete operations cognitive stage (Piaget, 1955) and the learners' psychosocial need to explore and to exert a sense of power and control over their environment (Erickson, 1950).

Goldman, Eguchi, and Sklyar (2004) conducted a study designed to engage inner-city students (ages 14-16) in Harlem with technology through educational robotics. Constructionism along with constructivism, Learning by Design, and Cooperative Inquiry guided the program. Students constructed and programmed robots to complete challenges. Similar to the outcomes of the Bers et al. (2002) study, these teen students developed self-confidence by overcoming initial hesitations and engaging in the program. Motivation was enhanced by the opportunity to demonstrate their projects to their parents. A similar study conducted by Williams, Ma, Prejean, Ford, and Lai (2007) demonstrates that middle school students participating in educational robotics in a two week summer camp improve their knowledge of physics.

Ostashewski, Moisey, and Reid (2010) demonstrate constructionism with an adult population. Teachers were trained to use LEGO robotics-based pedagogies in an online professional development courselet.

Participants not only constructed a robot artifact, participants also constructed blogs for sharing photos and videos of their constructed artifacts, participated in sharing files related to educational robotics and teaching strategies, and collaborated in an online social media based discussion forum. The researchers indicate, “according to constructionism theory, tools, digital media, artifact construction, and reflective discourse on the artifact are the basis for knowledge construction” (p. 724). Ostashewski et al. also note the tremendous potential of the social media web for allowing students “to construct and share their digital artifacts instantly with others around the world…” (p. 724). Findings indicate the online courselet content, the delivery method, and the social media framework were valuable to participants and contributed to achievement of learning goals. The study demonstrates the usefulness of a constructionist paradigm for online professional development. While we have emphasized robotics with regard to RILE and constructionism, AF-TEL may be used to align theories with desired learning outcomes across a wide variety of learners and contexts.

TEACHER PROFESSIONAL DEVELOPMENT

The AF-TEL framework may be applied to the broader context of teacher professional development. This context may include a variety of technologies in addition to the robotics associated with RILE. Professional Development for STEM Teachers using Discovery Labs (PDSTDL) is a format of teacher professional development proposed to address the critical need of preparing effective STEM teachers by addressing two main gaps in STEM education. These gaps include the need for STEM teachers and STEM students who can not only consume the available STEM resources for their educational and personal needs, but also become contributing individuals to promote the field of STEM. A summary of the assessed needs and gap analysis from the student and teacher perspectives that provides a rationale for PDSTDL follows as well as descriptions of the technologies included in the Discovery Lab component of PDSTDL.

PDSTDL is designed to offer professional development to high school teachers in an effort to increase content knowledge using state of the art technologies combined pedagogical strategies that are grounded in research. This is in keeping with NCATE’s (National Council for the Accreditation of Educator Preparation) finding that “While content knowledge is important and necessary, it alone cannot determine whether the teacher is able to teach so that students learn” (p. 4). PDSTDL will provide professional development to STEM teachers with content knowledge and strategies to train STEM students to be globally competitive by preparing them to be able to (a) look at open ended problems that might have multiple solutions, (b) solve multi-step problems, and (c) use technology as a resource to solve problems.

In addition to ensuring that teachers increase their content knowledge, PDSTDL utilizes state of the art technologies, collectively called Discovery Labs. These technologies are tools which can be used in effectively and efficiently designing content related lesson plans due to their functionality and features. Among these technologies are 3D printing, mobile app and game development, robotics, and laser communications. Current research suggests that contextual relevance and use of technologies such as these contribute to the increase in student learning outcomes (Khamis, 2006; Mataric, Koenig, & Feil-Seifer, 2007; Whiteside, 2014). Through these technologies, students explore their topics using an open inquiry method, a technique shown to increase student comprehension (Garrison, 1999).

The faculty members involved in the PDSTDL come from various STEM related backgrounds, including Mathematics, Physics, Engineering, Applied Science, and Education with expertise of pedagogy and educational frameworks. Together, they lend their subject matter and technology related expertise to prepare materials and templates for teacher workshops and work with teachers in designing individual lesson plans. PDSTDL aims to encourage extensive teacher collaboration and participation with the faculty through a yearly professional development workshop. Research suggests that small groups are more effective in professional development activities (Steiner, 2004), therefore small groups and low professor to teacher ratios during the workshops is key. For every 20 to 25 teachers, two subject matter experts and one pedagogy expert work closely with the teachers during the workshop, discussing content knowledge, and effective and efficient strategies to best present a given topic. These larger groups of 20 to 25 teachers are into groups of three and supervised by the faculty mentors. Through ongoing activities and the yearly workshop, PDSTDL promotes teacher exploration of (a) how technology can be used to design effective lesson plans, (b) how technology can be used to look at multiple facets of any given topic, (c) how to embed word problems related to real life and use technology as a tool to offer a solution to the given problem, and (d) how to offer a contextually relevant learning environment for the digitally wired student.

Need for STEM Education

The millennial generation is heavily dependent on using and consuming technology for all their needs; however very few of them are being trained to make significant contributions to the growth and development of science and technology, one of America's greatest strengths. "Few Americans, if any, can recall a time when the United States was not the world leader in mathematics, science, technology, and innovation. For decades, America has known no rival." (Business-Higher Education Forum, 2005, p. 3). Partnerships among educational institutions, business organizations and individual citizens helped foster the innovative American economy, unmatched in the rest of the world. Innovative applications of mathematics and science put Americans at the forefront of the global economy. The nation's infrastructure for innovation put a man on the moon and a vehicle on Mars. But now, the United States is losing its edge in innovation and is watching the erosion of its capacity to create new scientific and technological breakthroughs. Business Higher Education Forum finds that, "Increased global competition, lackluster performance of students in mathematics and science education, and a lack of national focus on renewing its science and technology infrastructure have created a new economic and technological vulnerability as serious as any military or terrorist threat." All data point to the fact that American school children are being out-smarted by their international counterparts in the area of mathematics and science.

Only 13% of 4th grade students and 7% of 8th grade students achieved an advanced level compared to 43% of Singaporean 4th graders and 48% of Singaporean 8th graders (Provasnik et al., 2012). Among the 34 OECD (Organization for Economic Co-operation and Development) countries, the United States performed below average in mathematics in 2012 and is ranked 27th in mathematics and 20th in science. There has been no significant change in performance over time. The need for students trained in STEM fields is growing exponentially and there is a huge gap in filling this need (Snyder & Dillow, 2013). StemConnector, a Cisco sponsored project, predicts the manufacturing sector will face a large shortage of employees with STEM skills. Alarmingly, 600,000 manufacturing jobs are going unfilled in the US in spite of current economic conditions. Between 2011 and 2015, an estimated 1.7 million jobs will be created in cloud computing in North America. By 2018, the bulk of STEM jobs will be in computing (71%) followed by traditional engineering (16%), physical sciences (7%), life sciences (4%) and mathematics (2%) (Munce & Fraser, 2013),

Teacher Preparation

The demand for preparing students to join the STEM workforce requires the preparation of STEM teachers to effectively educate and mentor students to prepare them for college and their careers, fill the need for STEM graduates, and contribute to the growth of STEM fields. This need is relevant for any nation seeking to excel on the forefront of technological innovation. In the US 11.5% of math, 19.7% of chemistry, and 20.3% of physics teachers in the 9-12 grades are not certified in their subjects, nor did they major in a related field in college (Hill, 2011). Just over half (52.8%) of earth sciences teachers are not certified and did not major in the subject area. With regard to mathematics, future high school teachers take on average only two college mathematics courses (Hill, 2011). This lack of preparation and subject matter expertise has an effect on student achievement, especially in mathematics and other STEM-related disciplines (Ball et al., 1999; Hill, 2011). Teachers who had professional development and gained subject matter content could use their knowledge to teach students to not only calculate correctly but also to use pictures and diagrams to articulate their solutions (Ball et al., 1999; Shulman, 1986; Wilson, 1987). Additionally Hill (2011) found that providing teachers content matter expertise positively influenced student-learning outcomes. Researchers have found that teachers who took higher level math and science related courses in college had a direct correlation on student achievement (Ball et al., 1999; Hill, 2011; Hill, Rowan, & Ball, 2005).

The Technological Pedagogical Content Knowledge (TPCK) framework provides a foundation for research and practice regarding teacher knowledge and technology integration (Mishra & Koehler, 2006; Yurdakul, et al., 2012).This framework, now referred to as TPACK, has emerged as a viable framework for teacher professional development (Polly, 2012) and it aligns with AF-TEL and PDSTDL. Pedagogical Content Knowledge (PCK) serves as the basis for TPACK, describing the dynamic interplay between teachers' knowledge of content and teaching strategies for useful representation in a learning environment (Mishra & Koehler, 2006; Shulman, 1986).

The increase in technology integration in educational environments stimulated the need for the unifying TPACK framework, providing researches and practitioners an organizational scheme regarding the interplay among teachers' technology, pedagogy, and content knowledge. Technological Content Knowledge (TCK) includes how various representations of content may be used in learning environments. Technological Pedagogical Knowledge (TPK) relates to the technology enhanced strategies used. The integration of all three components of the TPACK framework--technology, pedagogy, and content--provides a professional development learning framework containing the many facets of emerging technologies, pedagogical strategies, and concept representations for learning (Koehler, Mishra, & Yahya, 2007; Mishra & Koehler, 2006; Yurdakul et al., 2012).

Both AF-TEL and PDSTDL incorporate these findings in designing an effective learning environments and professional development for STEM teachers with specific regard to technology and pedagogy. Through teachers' use of AF-TEL, the cognitive, psychosocial, and pedagogical aspects of technology integration are emphasized so that beneficial integration related to learning outcomes is the result. PDSTDL ensures that teachers receive professional development that increases their content knowledge, prepares them to become effective STEM teachers, and emphasizes connections among STEM disciplines through hands-on examples related to real life scenarios using state of the art technologies. The project design also includes an evaluation plan that measures the success and impact of the professional development offered during the project.

Discovery Lab Technology

Providing a base for the Technological Pedagogical Content Knowledge framework is our innovative Discovery Lab Kit. Based on prior research (Department for Education, 2013; Johnson, 2003) and projects used in pilot phases at the current institution, the Discovery Lab brings together some of the most cutting edge technologies such as 3D Printing and Mobile App Development, bound in a custom software interface that allows teachers and students to benefit, to spend the limited available classroom time on using technology as a tool versus spending time learning the technology itself and its workings which may be outside the scope of the high school classroom. The software interface hides the complexities and provides a user friendly-user interface (UI) for each of the technologies for teachers and students so they can concentrate on using the technology to solve the given real world problems. Comprised of four technologies, 3D printing, mobile app and game development, laser communications, and robotics, Discovery Labs represent four distinct paths within STEM while still utilizing the content knowledge of mathematics and physical sciences taught in middle and high school. Previously, the use of these technologies posed two large obstacles: (a) teachers were not properly trained to use the equipment and (b) limited content knowledge has been attained to justify the cost. To solve these problems, the system is wrapped in a user interface to provide only the features necessary to train the teachers at a two week yearly conference, part of which is dedicated to developing lesson plans and content. Ongoing system access and support is available throughout the year. Some specific descriptions of each technology, as well as examples that each could be used for are presented below.

3D Printing

The 3D Printing Lab includes all the hardware required to print pre-created class materials, as well as student built items through in-class activities. While 3D Printing normally requires professional CAD software with a steep learning curve, a simple web interface providing only the functionality required for the algebra and geometry labs is provided. Students and teachers who want to bypass the system's interface can use a full CAD environment also loaded on the provided computers. Because the typical system is web-based, any computer on the school network (or over the Internet, if allowed by the school) can be used. Students typically work in groups on projects such as: (a) building an algebraically defined floor plan, (b) slicing shapes to determine cross sections, and (c) building custom shapes to fulfill geometric constraints. When students are ready to print their object, they send it to the teacher's queue, which allows the teacher to print six items simultaneously, in as little as a class period. Items will be tagged with the student's name automatically, mailed the same day, and will be ready for further analysis.

Mobile App and Game Development

Mobile apps have become a primary source of information for students and teachers, and while many apps allow content creation, not many platforms offer app creation. Within this lab, students use a simplified interface to customize app templates and build their own working applications for iOS and Android. Through this lab, students can use algebra and geometry concepts to create physics based games exploring the manipulation of kinematics equations, develop calculating apps to explore variable manipulation and understand matrices and algebraic series, as well as many other topics. Similar to 3-D printing, both a simplified and traditional interface are available, providing full app development functionality.

Robotics

Clever programing environments and cheap processors have made complex robotics available to the students and teachers alike. Basic robots can move with independent bi-directional motors; sense their surroundings via infrared, ultrasonic, and light sensors; and make decisions based on pre-programmed, mathematics based conditionals. Through the construction and programming of these robots, students not only get a great introduction to robotics, but can also apply algebraic skills through logical programming (Whiteside, 2014). Statistics and geometry topics can also fit in through algorithm analysis and shape reading and drawing.

Laser Communications

The laser communications lab station is designed to utilize the wave nature of lasers to allow students to explore waves, light, fiber optics, and sound. The basic setup of the lab station consists of a laser device, connected to an audio source and a receiver connected to a speaker. The laser light will then transfer the audio, via a wave, to the receiver. Within this setup there are numerous mathematical applications and analyses, including 2-D and 3-D angles, sine and cosine wave analysis, and speed of light calculations. Similar to the other labs, a user interface is provided to measure wave statistics, modulate audio, and other related features. Together, these four lab stations represent a base of technology that permeates nearly all focuses of the high school mathematics curriculum, while maintaining relationships in numerous science benchmarks and providing an engaging learning environment for students.

Lesson Plan Creation

In order to facilitate teacher lesson plan development, a flexible curriculum framework based around the typical nine weeks pacing guide is used in order to create vertical and horizontal alignment of the STEM curriculum within the academic context. Teachers work during the two week yearly conference held each summer and throughout the year to develop lesson plans to utilize the provided technology and their newfound technical skills. Lesson plans are created by teachers and shared within the community and the schools where they teach. The yearly conference provides teachers with a central training opportunity, in which teachers learn how to integrate relevant technologies, expand their lesson planning skills, and cultivate participation in a learning community for future participation and expansion.

During lesson plan creation, emphasis is placed on the 5E model: Engage, Explore, Explain, Elaborate, and Evaluate (Bybee, 1997). Within the Engage section, an emphasis is placed on individualized learning through the addition of linked prerequisites, in which lesson planners create an activity to test student prior knowledge. Links to supplemental and remedial resources are provided if students are not prepared. The Exploration section focuses on promoting informed decisions and problem solving by using the provided technology, requiring group work and leadership, as well as a focus on combined math science and engineering topics. Each lesson is based on a real world scenario in which teachers can create linked lesson progressions. These characteristics of the lesson plans directly relate to the design of a modern 21st century STEM classroom for preparing successful STEM students using through effective STEM teachers.

In addition to lesson plan development, the development of Discovery Lab lessons develops teachers' computer literacy. While everything necessary to conduct and present the lessons is available without customization, lab interface controls can be toggled on and off, and certain options may be constrained, giving the teacher complete control over their lesson. If the teacher really desires, they may extend labs with extra modules or added options. A central forum space is provided for teachers to discuss their lessons and use of the system, where they will also be able to post comments, concerns and request features for the following years. This space will greatly improve online communication skills and bring teachers together.

Role of Learning Communities

Learning Communities will be used as a vehicle of implementation for the PDSTDL. A professional learning community in the context of teachers is characterized as an environment where teachers collaborate, and work towards improving student learning gains and increasing their rate of success. In addition, members in this learning community also offer emotional support, help each other in attaining personal growth, and encourage a synergy of efforts (Bielaczyc, 1999; Dufour & Eaker, 1998). Based on research suggesting the effectiveness of learning communities, several universities, colleges and schools in the United States have been pushing to embed this model into professional development activities. PDSTDL relies heavily on using learning communities to ensure the development of resources as deliverables and sustainability. Research suggests that institutions using innovative methods of teaching become self-sustained by including professional learning communities in the project. Research also suggests that to be competitive and successful globally, ensuring student learning is no longer possible by individual teachers. Collaboration among teachers and support from the whole school community is necessary to train students to be globally competitive. Learning communities provide such a venue (Giles & Hargreaves, 2006; Stoll, Bolam, McMahon, Wallace, & Thomas, 2006). To implement these learning communities, we will rely on the central online forum for teachers to share ideas. Within this forum, we promote learning communities by providing group threads, messaging services and Facebook integration.

PDSTDL addresses these goals by preparing the participating teachers to become effective by increasing their content knowledge, utilizing the advances in available technologies as tools to design effective curriculum, and delivering the content effectively. Teachers experience using technology to enhance their instruction, for example using robotics and 3D printing to teach content specific concepts. Similar results have also been reported by the Department for Education in the UK with the use of 3D printers in high schools improving student grades in mathematics (Department for Education, 2013). Through the

PDSTDL experience, teachers learn to use these technologies to effectively teach STEM content and to develop new lessons on their own. The goal of increasing the percentage of students performing at grade level will be addressed by well trained teachers and offering students the tools and technologies that help the digitally wired student to look at multiple facets of the same object of knowledge and decipher the content presented. Students will also learn to look at real world problems, analyze different possible solutions to these problems and rationalize their choices. Additionally by preparing teachers to offer advice and information on career choices and options available for STEM related disciplines and using technologies in the classroom to show their applicability to real world scenarios, PDSTDL will aim to increase student enrollment in STEM programs.

Dissemination and Sustainability

Sustainability is an extremely important aspect for any project to succeed. PDSTDL proposes the following strategies to ensure sustainability of the approach. Continued teacher communication will be fostered through the aforementioned learning communities for teachers to continue collaboration on their lesson plans and classroom experiences. The learning communities are informal and will contain a common forum for teachers to collaborate in a structured manner. The forums will continue to be monitored by faculty members associated with PDSTDL. Annual workshops will be established where participating teachers will join a one day conference to be organized in the school district premises. For schools to continue using their installed technology, yearly kits with a list of consumables will be created that allow easy purchase of these items. Because 3-D Printing is the most expensive kit, to allow schools to use only a few lessons which require 3D printing, a 3D Lab can be established at a location chosen by the school district to provide a shared printing service for all schools in the district. Schools will pay per print and prints can be delivered via mail or courier. Local businesses can provide specific lists of projects that would make an intern more likely to be hired. Local businesses may also be encouraged to offer internships for students so they gain real world experience while still in school which makes them more marketable after graduation.

SOLUTIONS AND RECOMMENDATIONS

AF-TEL is a viable theoretical framework whether it is applied to teaching physics through tele-robotics in RILE, or training teachers to effectively integrate technology in the broader context of STEM education through PDSTDL. Clearly, AF-TEL is adaptable and capable of embracing new theories while simultaneously incorporating relevant traditional philosophies of learning. In planning technology enhanced educational experiences, educators are directed to give careful thought to each component of AF-TEL, to acknowledge the interconnectedness of all the elements, and to align all the components to effectively and efficiently enhance learning. It is important to note that each of the five components of AF-TEL are adaptable in that the theories may be changed based on the age of the audience and the desired learning outcomes. The cognitive, social, and teaching presence components of the framework would include learning, psychosocial, and instructional or pedagogical theories related to the specific learners. AF-TEL is adaptable across all ages from early childhood through late adulthood.

FUTURE RESEARCH DIRECTIONS

The adaptability of AF-TEL for technology enhanced learning is timely considering emerging trends in education across disciplines outside of traditional colleges and schools of education. In a medical journal editorial regarding the new world of learning, Lucin and Mahmutefendic (2013) explore the constant acceleration of change. Recognizing that a “new, emergent, knowledge-based civilization” (p. 248) is replacing the vanishing industrial civilization, the authors stress the need for the learning process and understanding of the learning process to develop. Framed in an understanding of adaption capacity of the human brain, neuroplasticity, the authors cite evidence of adaption of the human brain to the digital era. The authors highlight the need for “continuous adaptation of the educational system and learning environments” (p. 256) and call for flexibility in accessing information through a variety of devices, focusing more on the development of learning skills, and adapting content and tools to the context of the digital age.

A review of engineering education reinforces the need for an adaptable learning framework such as AF-TEL. To address the high dropout rate in engineering degree programs and the low percentage of females in the field, Miller gathered a diverse team which included engineers, a physicist, mathematicians, a musician, and a historian (Miller, 2014). Miller states, “the new challenge is educating engineers, not for greater technical depth, but for being able to see the whole picture, so that they can recognize connections between problems that seem separate” (p. 17). Engineering programs should aim to develop creative innovators through a project-oriented, design-oriented curriculum (Miller, 2014). The need for developing creativity is also addressed by a movement to change STEM to STEAM in which the A stands for artistic thinking (Watson, 2013).

Although AF-TEL is useful, timely, and makes logical sense as an adaptable learning theory framework in this digital age, it is imperative that this framework be evaluated through educational research across multiple disciplines and contexts. While it has proven to be an effective framework for PDSTDL, AF-TEL needs to be researched in a variety of educational settings with various educational technologies and supporting learning, psychosocial, and instructional theories. It is only through such research that the viability and sustainability of AF-TEL will be determined beyond the current authors’ work with RILE and PDSTDL.

CONCLUSION

A viable contemporary theoretical framework referred to as the Adaptable Learning Theory Framework for Technology Enhanced Learning (AF-TEL) provides educators with a structure for integrating emerging technology into education. This framework is based on the cognitive presence, social presence, and teaching presence tenets of the Community of Inquiry model (Garrison, Anderson, & Archer, 2003) and directs attention to the who, what, why, and how of learning. The Robotic Interactive Learning Environment (RILE) combines robotics, web-based learning tools, and modern teaching approaches, and was the catalyst for AF-TEL. AF-TEL has been successfully integrated into Professional Development for STEM Teachers using Discovery Labs (PDSTDL) including 3D printing, mobile app and game development, laser communications, and robotics. With the vast expanse of theories, models, and strategies available to guide pedagogical decisions, educators are faced with the challenge of aligning technology and pedagogy with desired educational outcomes. Adaptable is a key word in AF-TEL and implies that this framework may be modified to fit many different settings with diverse learners, content, and educational technologies for a very broad range of technology enhanced learning experiences.

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KEY TERMS AND DEFINITIONS

Cognitive presence: The extent to which learners are able to construct meaning within a community of inquiry.

Community of Inquiry: A collaborative group of individuals that supports personal and mutual understanding of a given topic developed through critical discourse and reflection.

Instructional strategy: The process of organizing content and activities for learners to achieve desired learning outcomes.

Social presence: The extent to which learners are able to present themselves and their characteristics within a community of inquiry.

Teaching presence: The facilitation and organization of both Cognitive presence and social presence toward desired learning outcomes.

Technology enhanced learning: The application of information and communication technologies to teaching and learning for the purpose of motivating and engaging the learner.

Theory of Constructionism: The perspective that learning is most effective when the learner experiences constructing a meaningful product.