ENACTING STEM EDUCATION FOR DIGITAL AGE LEARNERS: THE *MAKER* MOVEMENT GOES TO SCHOOL

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ABSTRACT

The importance of STEM Education has become central to discussions about the future of schooling over the past 20 years. Predicated on the idea that a primary purpose of schooling is to prepare skilled and knowledgeable workers, these discussions have been grounded, in part, in cold-war era concerns about rapid advancements in STEM fields driven by more efficient and effective application of the systematic and structured ways of thinking that are common to these disciplines. However, curricula and pedagogical routines in these fields are fully established, and changing curricula, and reforming instructional practice, has been a daunting process. In this paper we examine the idea that educators can draw on the kinds of learning experiences that occur in informal educational settings, like *Makerspaces*, to shape in-school activities in ways that make learning STEM content more contextualized, authentic, and meaningful for students.

KEYWORDS

STEM Education, Problem-solving, Makerspaces, Project-based Learning

1. INTRODUCTION

The STEM acronym was coined by the national science foundation in the late 1990’s: to refer to the four separate and distinct fields we know as science, technology engineering, and/or mathematics (Sanders, 2009). More recently a cohesive conceptualization of STEM Education has emerged. *Integrative STEM Education* draws on the interrelationships among the four distinct disciplines, and focuses on constructing curricular and pedagogical approaches that help students develop ways of thinking and solving problems that are grounded in *purposeful design and inquiry*. This marks a distinct change in the ways educators think about teaching.

Developed at Virginia Tech, Integrative STEM Education is grounded in constructivism and draws on the findings of three decades of cognitive science research (Sanders, 2009). Integrative STEM Education principles include the idea that learning is a constructive, not a receptive, process; that motivation and beliefs are integral to cognition; that social interaction is fundamental to cognitive development, and that knowledge, strategies, and expertise are contextual (see Bruning, Schraw, Norby, & Ronning, 2004). When enacted, these principles draw on purposeful design and inquiry to “. . . provide a context and framework for organizing abstract understandings of science and mathematics, and encourage students to actively construct contextualized knowledge of science and mathematics, thereby promoting recall and learning transfer” (Sanders, 2009, p. 23). Central to this approach is the use of authentic, situated problems to drive the educational process. In this paper we examine the nature of STEM Education, the relationship between STEM Education and problem-solving, and describe some recent efforts to incorporate some of the principles that underlie the *Maker Movement* into K-12 education systems.

2. PROBLEM-SOLVING, STEM ED AND THE MAKER MOVEMENT

Solving problems is a routine part of the U.S. schoolchild’s day—although the kinds of problem-solving activities students typically engage in leave much to be desired. For example, school-based problem-solving in mathematics typically involves the explanation of a mathematical concept by the teacher (reinforced with information from a textbook), worked examples to model solution procedures, guided practice with a problem set, and independent practice with additional problem sets (homework). Problem-solving in science also tends to be procedural, with students working through problems on Punnett squares, acceleration of mass, or some other scientific conception, with occasional scripted verification labs that require students to follow the steps to arrive at the "right answer." In a technology class, assignments often include designing and creating a product (PowerPoint presentation, word processed document, spreadsheet, etc.), with problem-solving in this context involving figuring out how to create a product that meets the criteria established by the teacher. Engineering education, although largely absent in the k-12 environment, often draws on the problem set-activity that is prevalent in the kinds of mathematics and science problem-solving activities students engage in—especially in introductory engineering courses. These types of pedagogical practices continue to persist despite significant pedagogical and curricular reform efforts across all of the STEM content areas over the past 25+ years (e.g., AAAS, 1993; ABET, 1997; ITEA, 1996; NCTM, 1989, 2000)

It is, perhaps, not surprising that traditional pedagogy continues to endure in schools. Pedagogical reform is notoriously difficult (Richardson, Anders, Tidwell, & Lloyd, 1991), with entrenched teachers tending to teach in ways they were taught (Lortie, 1975) as they work within traditional administrative structures and employ the same didactic teaching methods that their teachers had used when they were students (Cohen, 1990). The emphasis is on transmitting discrete, inert knowledge that can be assessed using standardized tests; the school day is fragmented with separate periods for each subject—especially at the secondary level; teachers often lack deep and coherent understanding of content expertise; and there is a general lack of pedagogical sophistication and imagination. However, the post-schooling world increasingly requires individuals who can develop creative, sophisticated and elegant solutions to the myriad of social, political, economic, environmental, and security challenges facing our interconnected and interdependent world. Unfortunately, the isolated and oversimplified problem-solving activities that are so pervasive in schoolchildren's classroom-based learning experiences are not likely to promote the kinds of sophisticated problem-solving strategies necessary for addressing complex real-world problems facing our modern society.

2.1 Problem-solving and Integrative STEM Education

Jonassen (2011) proposed a taxonomy of problem types that include school-based activities like algorithms, story problems, and rule-using/induction problems, as well as more complex real-world problems like diagnosis-solution problems, policy-analysis problems, and design problems. His taxonomy is based on five external characteristics of problems: structuredness, context, complexity, dynamicity, and domain specificity. He claims the kinds of problems typically worked in schools tend to be more structured, contextualized, simple, static and domain specific—while real-world problems tend to be unstructured, context independent, complex, dynamic and domain neutral. Real-world problem solutions are hallmarks of "purposeful design and inquiry," fundamental principles of Integrative STEM Education pedagogy proposed by Sanders (2009).

As Butler, et al. (2014) said, "The integration of simple, yet powerful principles of learning into advanced technologies creates the potential to apply effective practices to education systems worldwide" (p. 332). The most exciting result is that as schools react to changes in our students' needs, they are beginning to incorporate ideas and strategies from informal learning environments that have not traditionally intermingled with formal educational institutions. To that end, the *Makerspace* movement has become a cultural phenomenon that is beginning to capture the imagination of educators.

2.2 Informal Education

Across the US, informal education has rapidly emerged as a way to provide opportunities for students to engage in meaningful learning outside of school. Lai, Khaddage, and Knezek (2013) suggested educators consider the "importance of recognizing students' technology-enhanced informal learning experiences and develop pedagogies to connect students' formal and informal learning experiences, in order to meet the demands of the knowledge society" (p. 414). Further, they consider a new way of thinking about learning within the concept of a learning ecology, which proposes "While students learn differently in school and out-of-school settings, learning can take place across boundaries, and what has been learned out of school can help shape what is learned in school" (p. 415). Cox (2013) reminded us that "research into students' use of technologies outside formal settings has shown that many students use it outside school even more than in school, and learning outside school is equally important in young peoples' development" (p. 15).

In a number of locations, informal education has rapidly developed in an effort to provide opportunities to students outside of school. Hung, Lee, and Lim (2012) define formal education as "school curriculum in which learning might be characterized as focusing on structured content, extrinsic motivation, and strict assessments" (p. 1072) and informal education as less structured activities, in which learning outcomes might not be explicitly foregrounded. Time and space is given for exploration, experimentation, developing interests, and intrinsic motivations. Assessments are less formal and might take the form of peer-recognition and critique to co-inform like-minded peers in their pursuits (p. 1072).

2.3 Bridging the Formal and Informal

Barron (2006) submitted that the literature on the importance of authenticity to learning is focused on either the formal or informal curriculum; therefore, it is important to look more closely at the interaction between the two. Literature on informal learning suggests that participants are "inclined to tinker, experiment, and 'mess around' with things as settings are relaxed and the stakes are low" (Hung et al., 2012, pp. 1077–78). More importantly, we agree with scholars who believe that it is important to find ways to blend the two (Shimic & Jevremovic, 2012). Erstad (2012) encouraged a view of "learning lives" as a way to examine all aspects of the ways learning occurs throughout one's life experiences. She reported that youths' time is consumed by formal school and media use, and suggested that "young people as learners move between different contexts of learning, both offline and online, in a constant flow of activity" (p. 26).

2.4 Makerspaces

Makerspaces, sometimes also referred to as hackerspaces, or fablabs, are creative, do-it-yourself spaces where people can gather to create, invent, and learn. Makerspaces are "places where learners have the opportunity to explore their own interests, to tinker, create, invent, and build…" (Fleming, 2015, p. 2) using a wide variety of physical and digital tools and materials. In libraries, they often have 3-D printers, software, electronics, craft and hardware supplies and tools, and more. While these began as community resources and in nonacademic settings, educational entities have quickly adopted the model; at first, only universities were developing them. Makerspaces were originally community-operated workspaces where people with common interests in computers, cooking, machining, fabrication, robotics, technology, science, digital art, or electronic art could meet, socialize, and collaborate. Although the topics may be disparate, they share "commitment to open exploration, intrinsic interest and creative ideas" (Peppler & Bender, 2013, p. 23). Makerspaces are located in community centers, libraries, museums, schools, and other formal and informal settings; while these began as community resources in nonacademic landscapes, educational entities have quickly adopted the model. Now we are seeing them begin to proliferate in K–12 too.

There is also a relationship between the maker movement and the effort to increase STEM-related curriculum and interest in STEM careers and to move beyond current careers to "make their own jobs and industries" (Peppler & Bender, 2013, p. 23). Hatch (2014) suggests the maker movement is actually an "internet of physical things" (p. 3) with physical objects connected via sensors to the internet. Martinez and Stager (2013) suggest that "making" is a pedagogical orientation; its strength is integrating creativity and imagination with design and encourages problem-finding in addition to problem solving. Further, making appears to stimulate creativity (Mitra, Dangwal, Chatterjee, Jha, Bisht, & Kapur, 2014).

New Milford, NJ high school, established a Makerspace in its media center and allows students to visit and work there whenever they have free time. Library media specialist, Laura Fleming, reported that it cost about $1,500 to get started since many items were donated. She says the students often start projects, but when they go home, they investigate further. In a school near Pittsburgh, PA, learners have the opportunity to build robots. The librarian/English teacher in the Cornell school district is using robotics kits in the classroom to build characters from stories students read. Using cardboard, pipe cleaners, and whatever else they come up with, along with the equipment in the kits created by Carnegie Mellon's create lab (motors, led lights, digital sensors), learners bring their characters to life. These represent just a few of the educators who are turning to hands-on projects that are part of the maker movement, including a growing network of do-it-yourself (DIY) enthusiasts. These teachers are leveraging learners' natural inclination to tinker and encouraging them to create projects from marshmallow cannons to hovercrafts that provide excellent learning opportunities.

3. CONCLUSION

Schools and schooling must adapt over time to meet the ever-changing needs of society, and the learners they serve. Informal learning contexts can motivate and engage learners by drawing on their interests and providing flexible social learning environments that promote active participation and meaningful learning through authentic activity. Conceptualizing, designing and creating products that meet real needs to address real problems provide excellent opportunities for learners to engage in the work of scientists, engineers, technologists and mathematicians and explore the relationships among them.

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