Inspired to Make

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Abstract

The purpose of this paper is to review the implementation and utilization of makerspaces to inspire the development of problem-solving skills within K-12 learning. There is consensus regarding the need for K-12 education to meet the needs of the 21st Century learner. Foremost among these needs, according to the Partnership for 21st Century Schools (2008a) are critical thinking and problem-solving skills. Based on the review of research, the authors present a brief history of the ways in which problem-solving and critical thinking have been addressed in the K-12 classroom in the past, and conclude with a description of how integrating makerspaces through STEM learning can impact and help develop these learning skills in order to meet the needs in the future job market.

Inspired to Make

There is, in the world of education, much discussion regarding the implications of the 21st Century society and the needs of the 21st Century learner. The evolution from the Industrial Age to the Information Age requires our education system to meet the needs of these 21st Century learners as they prepare for a society and economy very different from that of the past. Foremost among these needs, according to the Partnership for 21st Century Schools (2008a) are critical thinking and problem-solving skills. Researching the history of the ways in which problem-solving and critical thinking have been addressed in the K-12 classroom in the past provides us a glimpse of a path which leads from orderly lines of desks, restraining students as they memorize and regurgitate information – into a learner-centered, flexible workspace of today, where creativity and innovation work hand in hand developing technical knowledge and skills. Integrating makerspaces through STEM learning activities can help develop critical thinking and problem-solving skills in order to meet the needs of the next generation.

Critical Need for Creative Thinking and Problem-Solving Skills

Critical thinking, creativity, collaboration, and communication, also known as the 4C's, are regarded as some of the most important skills of the 21st century (Partnership for 21st Century Skills, 2008a). The significance of critical thinking is paramount in education, and its connection to the other 3Cs is equally valued. Leading experts on critical thinking stress the importance of its connection to creativity as well (e.g., Paul & Elder, 2006). Critical thinking can be broadly defined as "a developmental process that proceeds from experience (e.g., observation and interaction) to inquiry, investigation, examination of evidence, exploration of alternatives, argumentation, testing conclusions, rethinking assumptions, and to reflecting on the entire process" (Ma et al., in press).

Spector and Ma (2019) presented a framework of critical thinking with four dimensions: dispositions, skills/abilities, levels and time. Besides those dimensions, there are other essential elements of critical thinking such as motivation, criteria, domain knowledge, context, etc. The framework interpreted critical thinking from a holistic viewpoint and emphasized the dynamic nature of critical thinking in terms of a specific context and a developmental approach. The National Education Association (2011) defined critical thinking in four phases: to reason effectively, use system thinking, make judgements and decisions, and solve problems. Solving problems successfully and effectively requires a process of thinking critically. Simply put, the relationship between critical thinking and problem solving can be stated as follows, “Students who are able to think critically are able to solve problems effectively” (Snyder & Snyder, 2008, p.90). Developing problem-solving skills has been identified as essential to student success in the 21st century, not only inside the classroom but also in all professions (Jonassen, 2010; Kereluik, Mishra, Fahnoe & Terry, 2013).

Problem-solving skills have been researched for decades and the term problem-solving has been defined in various ways. For example, Kendler and Kendler (1962) believed that instead of being conceptualized as a basic psychological process, problem solving can best be conceptualized as one that reflects the interaction of more fundamental processes (e.g., learning, perception, and motivation). D'zurilla and Goldfried (1971), defined problem-solving as a behavioral process that provides different responses to problematic situations and increase the probability of success in effectively solving problems. They identified five stages of problem-solving: 1) general orientation, 2) problem definition and formulation, 3) generation of alternatives, 4) decision making, and 5) verification.

Problem-solving requires the ability to draw from previous experiences so the learner can apply what they already know from various content areas. Therefore, training students in problem-solving will mean educators need to allow them to "learn how to solve problems" and thus discover the most effective way to individually respond. An investigation by Phonapichat, Wongwanich, and Sujiva (2014) revealed that there were difficulties with elementary students’ mathematical problem-solving which included: 1) difficulties with understanding some keywords, thus they were unable to interpret them in mathematical sentences, 2) students were unable to figure out what to assume and what information from the problem was necessary to solving it, 3) students tended to guess the answer without going through any thinking process, 4) students were impatient and did not like to read mathematical problems. Those difficulties indicated the lack of robust problem-solving skills or the necessary training of critical thinking among those elementary students. Ultimately, the study verified that certain domain knowledge is necessary for the problem-solving process.

Just as elementary students struggle to learn problem-solving skills, it is evident that the lack of growth transfers through middle and high school as well. According to a report from Partnership for 21st Century Skills (2008a), 76% of the business leaders of U.S. companies surveyed indicated the significance of problem-solving skills and creativity and their inevitability to increase considerably in the workforce as the problems in need of solutions grow evermore complex. Additionally, those same leaders reported that there was a lack of critical thinking and problem-solving skills among hired high school students (Partnership for 21st Century Skills, 2008b).

In the recent standards of science education, critical thinking and problem-solving skills are emphasized (National Research Council, 2013). Through the process of problem solving, learners engage in critical thinking with the aid of creativity and design. Scientific investigation and engineering design are placed at the forefront of science and engineering learning in the next generation science standards (National Academies of Sciences, Engineering, and Medicine, 2019). Just as Silva (2008) notes “it is an emphasis on what students can do with knowledge, rather than what units of knowledge they have, that best describes the essence of 21st century skills” (p. 2). In order to prepare for the critical thinking jobs of the future, it is important to understand where the education system derives and how to continue molding and improving to fill the needs of the future job market. Unfortunately, there are very few states in the United States which have adopted or partly adopted the next generation science standards.

History of Problem-Solving in the Classroom

Within the U.S. education system, the skill of problem-solving has been addressed in different ways and different teaching and learning methodologies have been utilized to promote success. In order to appreciate the development of problem-solving skills in the classroom, it is important to review the progression of classroom structure and methods for teaching over the past half century. Starting with the “traditional classroom”, one can identify additional tools and methods that have been designed and added to advance critical thinking in the classroom setting over the years. These tools and methods include problem-based learning, STEM, STEAM and makerspaces.

The Traditional Classroom

To understand today’s classroom setting in U.S. schools, one must dissect how current learning is achieved and what might be missing in order to improve future educational practices. When researchers refer to the U.S. education system, there is often mention of the “traditional classroom,” yet that terminology is not always defined.

One descriptive definition found in literature (Hertz-Lazarowitz, 1992) describes the traditional classroom as a "single social system" (p. 73), with the teacher presenting herself as the center of activity, while students are isolated in rows of individual desks. The teacher "controls all communication networks and presents knowledge to pupils...The learning task is structured as individualistic or competitive...Student-to-student interactions are minimal, and each student looks after himself or herself." (Hertz-Lazarowitz, 1992, p. 73). While this type of learning was important during the industrial revolution in order to reach and teach the masses, the educational practices have changed little since then. This is despite that fact that digital technologies are changing not just how we live and work, but how we think and behave (Keegan, 2012). Additionally, researchers continue to impress upon educational leaders that teaching must advance and change from a teacher-centered to a student-centered experience (Froyd, 2008).

As a teaching method common throughout the 20th century, rote memorization appears in discussions of the traditional classroom, and, although there are arguments for the purposeful application of memorization in education (Caron, 2007), there are many voices urging the importance of escaping the perceived outdated reliance on rote memorization as the very definition of education (Canestrari, 2008; Fata-Hartley, 2011; Snyder & Snyder, 2008). Rote-memorization dates to Confucian education from early China and Tan (2015) refers to it as a form of surface learning as opposed to a deeper learning method. Surface learning or reproducing content is essentially the opposite of critical learning and thinking, which requires what is referred to as deep learning, or an "intention to understand content in order to relate and structure ideas" (Dolmans, Loyens, Marcq, & Gijbels, 2016). As the evolution of transformation in the classroom continues, so should the evolution of learning. Education should emerge from a method of surface learning and rote-memorization to a deeper learning structure integrating the critical thinking and learning processes laid out in 21st century skills framework.

Problem Based Learning

Problem based learning (PBL) is an educational method that introduces relevant real-world problems in the classroom in order to encourage deeper learning and critical thinking to design applicable solutions (Dolmans et al, 2016). In 1969, McMaster University first developed curriculum using problem-based learning as part of its medical school (Banta, Black, & Kline, 2001). In recent years, the Harmony Public Schools developed a curriculum that incorporates project-based learning into STEM called "STEM Students on the Stage (STEM SOS)" (Sahin & Top, 2015). The Harmony Schools curriculum was designed to help teachers by providing structure to what is often perceived as an unstructured teaching method.

STEM

For the last two decades the term STEM has become the focus of educational practitioners and researchers all over the globe. STEM was coined in 2001 by leaders at the National Science Foundation to describe curriculum that involved four different areas of learning: science, technology, engineering, and math (Patton, 2013). In 2011, the concept became more important with nationwide implementation through the federally funded initiative called Educate to Innovate. According to Ostler (2012) the problem that existed with this initiative was that all parties involved "markedly under-conceptualized what STEM education was" (p. 28) and how schools could and should implement the initiative. As a result, researchers have spent the past decade studying and learning effective ways to implement STEM learning. The U.S. Department of Education's (USDOE, 2018) website states, "If we want a nation where our future leaders, neighbors, and workers have the ability to understand and solve some of the complex challenges of today and tomorrow, and to meet the demands of the dynamic and evolving workforce, building students' skills, content knowledge, and fluency in STEM fields is essential." In fact, in 2018, the U.S. Department of Education surpassed President Trump's request for directing $200M to STEM learning, by investing $279M in discretionary grant funding (USDOE, 2018).

STEAM

Although the acronym STEM is wide-spread and is argued by many as encompassing all areas of learning, by 2018 there was a movement in education circles which argued for the addition of the letter A for art to create the word STEAM (Chu, Martin & Park, 2018). It is argued that the addition of Art into traditional STEM addresses the importance of creativity in education (Conradty & Bogner, 2018). Beyond that, there are those who argue that, when Art is integrated into STEM, "new understandings and artifacts emerge that transcend either discipline" (Peppler & Wohlwend, 2018, p. 1), thus enriching multiple content areas. For the purpose of this article, we will acknowledge Gerlach's (2012) concern with the fact that STEM "means so much for so many different groups of people" (para 9) - and use the acronyms STEM and STEAM interchangeably to focus on the common overall concept of using an interdisciplinary approach to solve problems within the realm of science, technology, engineering, and math.

Maker Movement and Makerspaces

There are those who claim that today's maker movement started with the inception of Make Magazine (Halverson & Sheridan 2014), while others would argue that the foundation of the maker movement can be dated back to Seymore Papert's constructionism, the theory that highlights the process of learning to learn and making things to help solidify learning (Pernecky, 2012). Regardless of when it started, the last two decades have shown a surge of research in the topic area that was virtually non-existent prior to the 21st century. The idea of Making or makerspaces over the last two decades have been referred to and researched under several different names including hackerspaces, fab-labs, and tinkering. Although other names exist, they all refer to the act of investigating, creating, remixing, designing, redesigning, fixing or tinkering in order to create and/or understand something (Moorefield-Lang, 2015). This paper will refer to the creative act of Making by capitalizing the term to help identify the process for which it is named. The result can be the creation of something that already exists, or it can be something entirely brand new. While collaboration may play a part, it doesn't have to be present in the process. The maker movement allows for a free flow of ideas from anyone who wants to take part in the Making, even if it is only just one person. As the maker movement gained popularity, President Obama presented the first White House Maker Faire in 2009 (Halverson & Sheridan, 2014). Obama focused interest on the educational community by saying "I want us all to think about new and creative ways to engage young people in science and engineering, whether its science fairs, robotics competitions, fairs that encourage young people to create and build and invent, to be makers of things, not just consumers of things" (Obama, 2010, p. 561). This type of vision can encourage a whole new generation of tinkerers and makers to develop and flourish and reinforces reason to study the impact of this creative learning methodology.

Maker Movement's Role in Critical Thinking and Problem-Solving Skills

Eleanor Roosevelt, in her book Tomorrow is Now (1963), shared: "It is one thing to provide a simple skill that can be applied to a given situation. It is quite another thing – and a new, a revolutionary thing – to prepare young people to meet an unknown world..." (p. 66). Understanding the history of problem-solving and critical thinking in education allows researchers to better design a course of action for improving learning for the future. Knowing what has worked historically – and where the shortfalls are – creates a path for others to navigate and design new methods for learning and developing future generations of critical thinkers. Inspiring students to problem-solve in a makerspace using the problem-based learning approach to solve real world STEM problems is just one of the ways makerspaces have invigorated the role of the learner and helped educators and scholars to see unique ways in which to challenge students to become natural problem solvers (Slatter & Howard, 2013).

Makerspaces by Design

Makerspaces can be designed in a multitude of ways. One of the best parts of makerspaces is that it is created to benefit the community in which it is placed, so each one can look uniquely different (Oliver, 2016). Community and school libraries host the greatest number of makerspaces, as their design by nature lends itself to the activity (Colgrove, 2013). There are many reasons why libraries and makerspaces go together. These include: 1) creating purpose for visitors to come in and use the facilities, 2) their wealth of resources enhances the learning before, during and after any build, 3) community experts have a place to share their knowledge with others, and 4) they enhance community outreach (Slatter & Howard, 2013). While communities may have a host of other, additional, reasons to implement a makerspace, each reason provides an opportunity to help develop the people and the community.

Schools have also joined in on Making and started implementing makerspaces to increase student engagement, enhance problem-solving skills, and to improve collaborative learning opportunities. When implemented in schools, the designers of the spaces have created all types of unique spaces for their students. In some elementary spaces you may see Lego walls or tables (Medlar, 2016), computers of various sizes and shapes, or even brown paper bags full of elements such as straws or toothpicks, cotton balls or bottle tops – often with a challenge written right on the front of the bag. These tools may be mobile in order to conserve space and allow for ease of display when needed for use.

In middle schools and high schools, you are likely to see larger spaces and often permanent ones that are set up in a classroom or, more often, in the library. The spaces usually have flexible seating for easy movement and collaborative working. Tables are typically taller to accommodate both standing or sitting on a tall stool. Often, there are computers and 3D printers (Moorefield-Lang, 2015) flanking the space and research books to aid in learning. These spaces usually have simple tools, such as scissors, markers, poster board or poster paper and more complex tools like switches, motors, circuits and even robotics of various types and brands (Oliver, 2016). Librarians will keep old or retired books in the space for recreating new works of art. There are often Arduinos (Gustafson, 2013) for the building of electronic pieces that can do or accomplish things with computer programming. If messiness is allowed in the space, like a mess one might find in a shop, the space may hold welding tools or woodworking tools for bigger builds. Each space is designed specifically for the students it serves with the budget available or set aside for that school or space.

Multiple makerspaces to accommodate different situations is even likely in some locations. Many of the larger colleges don't stop at just one makerspace. At many universities, you may find upwards of five or six spaces around campus. Colleges like the University of California at Berkeley, University of Washington and Princeton all boast about the size or multitude of makerspaces around their campuses. Colleges are even seeing the value in places and spaces for innovative design and collaborative creations. Some of the greatest creations came from garage makerspaces before their time. Consider the beginning of Microsoft and Apple. Makerspaces can produce inventions and discoveries whether it is in a school or somewhere else in a community. These spaces drive innovation and allow the mind of any age to think deeply and critically while developing a solution to what likely started as a simple question: I wonder...?

Problem-Solving in Makerspaces

Cooper and Heaverlo (2013) found that problems and their potential solutions are a common driving force in motivating students to want to learn. While motivation is important, they also discovered that collaboration is another key to problem solving, which lends itself to the design of makerspaces. With the collaborative design of a makerspace it becomes a natural environment to create cross-disciplinary problem-solving activities which can "foster higher levels of epistemic and intellectual development in students" (Cooper & Heaverlo, 2013, p. 27).

In many educational circles today, Making is employed as a major approach to developing problem-solving abilities among children. However, regardless of approaches adopted to develop problem-solving skills, it is not a simple idea. It involves conceptual knowledge and procedural knowledge, and consequently there are rules for the development of these skills, according to Riley (1984). With age, children's improved ability to solve word problems primarily involve an increase in the complexity of conceptual knowledge required to understand the problems' context. Therefore, the development of conceptual knowledge requires the consideration of the sequences of different types of problem-solving skills and one's progress should be aligned with the stages of child development.

In order to encourage children's problem-solving abilities, there are many developed and well-established approaches that have been researched. However, current scholars in K-12 learning specifically call on the movement of Making. Martin (2015) argued that "Making gives youth access to sophisticated tools for building and for thinking" (p. 36). One example is the increasing awareness and development of creativity among children - especially in STEM fields. Taylor (2016) evaluated the benefits of the maker movement in K-12 education and believed that Making allows students to connect the hands and the mind in a cognitive and physical capacity, preparing them with 21st century skills. With the understanding of the research and a clear pathway for learner's success, Making can be the cornerstone of future educational approaches to critical thinking and problem-solving. Sheffield, Koul, Blackley, and Maynard (2017) argued that "a makerspace approach to STEM education can be an authentic and robust pedagogical practice providing there are strong and explicit connections the curricula of mathematics, science and technology and the resultant [makerspace] product..." (p. 152). As is the case with any new tool, only if the makerspace is implemented effectively will it enhance learning and help to develop the desired critical thinking and problem-solving skills.

Implementation of STEM Makerspaces

One of the most time consuming and difficult parts of implementing any new learning practice or tool for teachers is creating effective strategies for teaching and learning Bevan, Gutwill, Petrich, & Wilkinson, 2014). With makerspaces, it becomes even more difficult because teachers often still have the traditional classroom mindset and must guide and develop the student's abilities to a point that they can be released to create and discover on their own (Bevan et al., 2014). It is the release of ownership from teacher to student that allows the student to develop the critical thinking skills necessary to meet those standards needed in the future workplace. As students begin to develop the confidence in their own confusion and struggle, to, ultimately, discovery and success, their confidence helps them to pursue additional goals with less hesitation. When this process can be achieved in an engaging activity such as those a makerspace can offer, students become eager to learn and to keep moving forward. When teachers can see success in students, they, too, can become more invested in the design of makerspaces and their abilities to guide learning without being the center of learning activities. As the students learn through gradual ownership, teachers learn through the process of gradual release of responsibilities.

Bevan et al. set out to design a framework to help teachers and faculty effectively implement tinkering activities into the classroom curriculum (2014). The team consisted of researchers and practitioners so that research supported techniques and practical application could join to create an effective plan for the future of makerspaces in communities and schools. The resulting framework is widely used today by practitioners in the educational field and beyond. The study focused on tinkering in the area of STEM learning through afterschool programs. What resulted was four dimensions of learning: "engagement, initiative and intentionality, social scaffolding and developing understanding," (Bevan et al., 2014, p. 106) The team concludes that there is great potential for tinkering as a tool for learning (Bevan et al., 2014). While they know that theirs is just one tool for capturing learning, it is a solid researcher and practitioner-based start for STEM and makerspaces and an engaging opportunity for future critical thinkers.

Conclusion

We live in a time where people often discover success purely by accident. To believe that we can predict what tomorrow will bring in the way of successful careers and opportunities would be misguided. As researchers and practitioners in the educational field know, success often depends on the simple act of trying and then trying again. That saying often holds true in the implementation of, and activities within, makerspaces as well. If we do not attempt to find new and innovative ways to inspire future generations moving through the educational system, the outside world will continue to be more interesting and the world within the school walls will become irrelevant – and simply put, a means to an end. In order to inspire discovery and meet the dire need for critical thinking, it is important that we help learners develop the problem-solving skills needed so that when faced with new opportunities for growth in learning, they become inspired to move forward with the challenge.

As STEM learning allows for a cross-curricular training in unique skillsets, so too does the marrying of STEM and makerspaces for learning those skills. These environments are safe places for students to attempt creation, to fail, and to collaborate with others in the reattempt for success. Without opportunities like these, we often find the learner and the educator stuck in the rut of traditional classroom learning. It is the authors' intent to bring attention to the marrying of STEM and makerspaces to engage budding problem-solvers and help them to develop the needed skills for tomorrow's careers. It is also our hope to encourage teachers to challenge their own abilities with the implementation and integration of cross-curricular spaces for student Making. Together, we can build opportunities and experiences that will encourage the next generation of students to go beyond their comfort zones, be excited to learn, and more specifically, inspired to Make.

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