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# Project-/Problem-Based Learning in STEM: Impacts on Student Learning

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feature article

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*Educators have a unique responsibility to expand, while at the same time ground, [student] curiosity by developing activities that foster learning of various concepts, ideas, and ultimately prepare students to apply these experiences in real-world situations.*

by
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## STEM Beginnings

Children have been taught STEM-related subjects for decades, from dissecting frogs to building makeshift volcanoes that spew baking-soda lava. Students use engineering and math skills to build bridges out of toothpicks. The problem is, most of this learning occurred as part of an education system that merely put students in a "box," with each subject taught as a stand-alone block of instruction and no clear connection to other areas of study. A new teaching and learning approach was needed.

The Soviet Union's launch of Sputnik in 1957 was the catalyst for setting STEM in motion, prompting congress to pass the National Defense of Education Act in 1958 (Jolly, 2009). The concern was that American children were inferior to Soviet children in science, and the goal was to create an elite generation of STEM workers (Passow, 1957). Over the years, students became technologically literate by learning concepts such as product design and manufacturing, problem solving, and consideration of technological impact on the environment and society in general. Guiding these new concepts is a pedagogical learning tool: *Standards for Technological Literacy* (*STL*). The four *STL*-related goals are to:

1. Establish a common set of expectations for what students in technology laboratory-classrooms should learn.
2. Ensure that the learning is developmentally appropriate for students.
3. Ensure that the learning provides a basis for developing meaningful, relevant, and articulated curricula at the local, state, and provincial levels.
4. Ensure that the learning promotes content connections with other fields of study in Grades K-12.

(International Technology Education Association, 2007)

The STEM concepts and skills students develop are vital to their future success, both in the classroom and, most importantly, to meet the needs of today's workforce. STEM education differs from other traditional classroom environments primarily through the use of Project-/Problem-Based Learning strategies.

Project-/Problem-Based Learning creates dynamic learning environments, incorporates various stimuli, allows learners to gain valuable experiences that extend to real-world applicability, and should be considered as a primary delivery method in STEM classes. Scott, (2017) points out "PBL was first used in the 1960s to help train medical students to develop patient diagnostic skills (p. 1)." It also helped develop collaboration and teamwork skills in order to solve complex medical problems. According to Hung, et al. (2008), "PBL migrated into other training environments and eventually migrated into K-12 education and postsecondary classrooms" (p. 2). The application and benefits of PBL in STEM classes are limitless. Students learn team building through collaboration/brainstorming; learners create strategies to achieve a goal or objective and develop leadership and critical-thinking skills. These are valuable attributes both for students in the classroom and the workforce of the future. According to Volkema (2010): "There is a set of sociocultural skills that are central to the effective functioning of a project management team. These include team building, meeting management, problem solving, and negotiation/persuasion/conflict management skills (p. 11)." Another key aspect of the PBL process is Return on Investment (ROI), an economic analysis of data that is compiled during a project to determine if the financial gains are worth the financial risks of technological product research, development, mass-production, and sales (Wright, 2012).

PBL brings a multilayered/theory/skillset approach to learning. Project-/Problem-Based Learning requires students/trainees to use critical-thinking processes throughout the assigned project. Learners pull concepts from Cognitive Learning Theory (Piaget, 1936), as well as incorporating skills associated with Behavioral Learning Theory (Thorndike, 1905). They also use concepts derived from Constructivist Learning (Dewey, 1910), which are designed to foster learning using knowledge developed from previous life experiences and the application of those experiences to new concepts. By working in groups, elements of CLT, such as the social and environmental elements of Social Cognitive Theory (Bandura, 1986), and the self-reflection aspects of Behavioral Cognitive Theory (Brownell & Jameson, 2004) emerge. Interaction and collaboration with others to solve complex problems, as well as going through the various steps of the process in order to achieve a goal, are key to a successful STEM project.

## Project-/Problem-Based Learning and STEM Teaching and Learning Strategies

Students must have the proper mindset towards the project. According to Johnson, et al., "Individuals who approach a learning situation with the goal of developing their skills rather than the goal of performing well, are said to have adopted a Mastery Goal Orientation (MGO) in that context (also often referred to as a learning goal orientation) and are, therefore, more likely to benefit from that learning experience" (p. 2). Students must develop working knowledge of the steps of the problem-solving process. The number of steps depends on the scope of the problem learners are solving. As STEM is the focus of this article, the following four-step problem-solving process will be discussed: 1. Identify the problem or opportunity, 2. Devise a plan for solving the problem, 3. Implement/Evaluate the plan, and 4. Communicate the plan/solution (Wright, 2012).

***Identifying the problem/opportunity.*** What is it they are being asked to accomplish? Teams develop, or in some cases are given, a problem statement and begin to build a plan/strategy around this idea. Group-developed problem statements give groups a sense of ownership, especially if they identified the problem/opportunity in the first place. Problem statements provided to a group offer opportunities for students, instructors, and course designers. From a STEM instructor's or designer's perspective, a strategy might be to purposely present the group with a project that is, according to Stefanou, Stolk, Prince, Chen, & Lord, "ill-defined, complex, and open-ended, sparking increased higher-level cognitive strategy use among students" (p. 9). These types of scenarios give teams the responsibility for filling in the gaps, developing criteria and constraints, and gathering information relating to the technological, scientific, legal, and societal knowledge required in the development of the solution. This sets the tone for the project and requires groups to work together immediately rather than wasting time socializing and/or not taking the project seriously. Once information is gathered, teams move on to the next step of the problem-solving process; Devising a plan for solving the problem (developing preliminary design solutions).

***Devising a plan for solving the problem*** is a critical part of the problem-solving process and one that must be conducted in a thorough and complete manner in order to give the project the

best chance for succeeding. Team members devise multiple suggestions to consider regarding the solution. This is a rapid-paced, throw-caution-to-the-wind exercise, where any and all ideas are presented and recorded for further discussion at a later time. These situations are often called brainstorming, or "what-if" scenarios. We begin to see the connections to Experiential Learning Theory, which, according to Quinn & Bunderson, is when "learning requires drawing differing beliefs and ideas out of people because differences help individuals revise perceptual frames" (p. 5). Using the developing/designing of solutions process, provide teams with options on how to tackle the problem. Ideas are put on paper in the form of simple sketches or drawings, then later refined into detailed sketches that give the team a three-dimensional representation of their technological artifact/product. Teams move to the next step of the process.

***Implementing and evaluating the plan.*** Team members decide how to best represent the artifact/product they are developing. Examples include 3D graphic models, which are used to illustrate the relationship between components and physical models, or mock-ups, to provide a structural and aesthetic view of the proposed design. They can be as simple or as complex as the team deems necessary to evaluate the design. Cavalcante Koike, Viana, & Vidal, (2018) point out, "Teams may use prototype manufacturing to show whether the project included functional models built by the students and used to define if the project/team are achieving the previously defined aims" (p. 10). For STEM-related projects, prototyping is a key element in the learning process, as teams transition from primarily cognitive-related skills, to more behavioral/constructivist skills. These skills are vital not only to the project but pave the way for individual team members to develop self-efficacy through being challenged to perform tasks that take them out of their comfort zones. Brownell & Jameson (2004) point out, "PBL's goal is long-term learning that results in behavioral change and not just conceptual mastery" (p.3).

Team members can showcase STEM-related skills gained by previous experience. They may also learn new skills such as using basic hand tools, operating machinery (CNC, 3D printers, laser cutting), performing molding and casting functions, assembly, or assisting with some other manufacturing-related processes. The key in this stage of the project is to give learners a sense of ownership in the creative, hands-on aspects of the project. Once the model, or prototype, is developed, the team will begin analyzing the artifact by performing analysis of the functionality, specifications, ergonomics, and, when applicable, the potential return on investment (ROI). This will depend on the nature and scope of the project. Teams may discover design flaws ranging from structural integrity, being out-of-specification, or other issues that must be addressed. Some issues might be relatively small and easy to fix, while others may require an entirely new design. These are routine matters that teams must be prepared to deal with. However, depending on the team dynamics, including age of the students (especially elementary-level students), individual egos, maturity, level of team cohesiveness, etc., these issues can have enormous impacts on the project's outcome. The team leader, with assistance from the teacher/instructor, works to get the team back on track. A good teacher/instructor will devise a way to refocus the team on developing a workable solution and redirect their negative energy towards a more positive one.

Students need reminders that the purpose of following the steps and procedures of the problem-solving process is to make discoveries, both good and bad, and that working as a team to develop strategies that will help them overcome adversity is just part of the learning process. They must also remember that the activity is a team effort, and their commitment is to the project, not themselves. According to Stolk and Harari (2014), "Research shows that several aspects of motivation are particularly important in cognitively demanding tasks: goal orientation, perceived value, and self-efficacy. Motivational studies conclude that students who adopt intrinsic, learning-oriented goals are more inclined to find value in the learning, adopt deep cognitive strategies, and attain better performance, compared to students who focus on extrinsic rewards or performance goals (p. 7)." These are important teaching points as well as an opportunity for individual student cognitive growth.

Teams face numerous challenges throughout the project, and keeping members motivated is a key element of the project. One area of concern is individual and team stress, perhaps resulting from decisions regarding design, types of modeling to use, prototype production, or potential deadlines that must be met along the way. According to Savelsbergh, Gevers, van der Heijden, & Poell, (2012), "Teachers/instructors need to act as project managers who perceive signals of individual or shared role stress and should stimulate members to collectively explore and reflect on the role division in the team; opening up the opportunity to experiment with a different role division and a reallocation of resources, to safeguard the effectiveness of the individual team members as well as of the team as a whole (p. 24)." Teachers/instructors must take action in cases where the stress atmosphere among individuals or teams is tangible. Otherwise, project success is almost certainly unattainable.

Teams may have to tweak or completely overhaul their design concept, create a new model, and be prepared to test and re-evaluate the newly produced item. Teams enter a new dynamic in the project—situated cognition—and the effect of product dissection. According to Grantham, et al., (2013), "To investigate the impact of product dissection on cognition, the classroom activity must be categorized with a cognitive framework. Situated cognition is a theory used to describe the context of a learning activity's effect on learner's cognition (p. 4)." Learners reflect on what may have led to the failure of their product. Through dissecting/disassembling and analyzing the individual components, the team may discover design or manufacturing flaws and make the necessary changes/adjustments to perfect the product. Once the team has successfully tested/evaluated the product, it is time to bring the completed project to the approving authority, which in this case would be the teacher/instructor.

***Communicate the plan/solution.*** The methods of communicating the results may vary. For simple designs, a brief discussion from a selected member of the team will suffice, while very large and/or complex projects will require much more detailed information to be shared/presented by the entire team. Documents and written reports may be reviewed; detailed engineering drawings with specifications, assembly, and other material information need to be communicated. The idea is for the team to articulate the processes they went through during the course of the project, what worked well for them, what challenges they faced, and more importantly, how well they responded to those challenges. The team's artifact should be prominently displayed for discussion via question-and-answer format in order to critique and evaluate the team's mastery of the various tasks required throughout the project. Each member of the team should be prepared to discuss their involvement in each phase of the project.

Teachers should include a requirement for a written reflection, using multiple questions to prompt/guide students to revisit each step of the problem-solving process, team interaction/cooperation, and any key learning skills developed or refined during the project. This is done to gather as much feedback as possible from each student to not only help capture student experiences and comprehension of project-/problem-solving concepts, but to help make adjustments/improvements to the project for future classes. This is just one example of a project-/problem-solving process and the important role it plays in STEM education. Of course, there is always room for improvement.

## Improving STEM With New Strategies

Projects are often designed for short durations, some in as little as one class. As educators, it is incumbent upon us to challenge students using diverse pedagogical strategies. One solution, according to Habron (2015 p. 2) is to "develop a semester-long project that requires students to work through the project-/problem-solving processes in the form of an eportfolio." This is an important pedagogical strategy, designed to allow students to showcase their academic efforts over time. Students working in groups can build their eportfolios based on the project requirements. Predetermined checkpoints are built in to allow the teacher to evaluate team progress and provide support to help overcome any obstacles or problems encountered during the different phases of the project.

Well-designed eportfolio projects require teachers to provide specific guidance to students on the expectations and goals of the activity/project. As Scholz, et al., (2017) point out, "Successful eportfolio activities are operationalized as exhibiting alignment of expectations between students and instructors, whereas misalignment of expectations is characteristic of a poorer experience for the learners (p. 3)."

Teams need to understand that the project's purpose is for individual growth and development of new skills, and teachers must reinforce this point at every checkpoint. Research has expressed, perhaps unsurprisingly, the challenges that arise when adopting a tool or learning activity as potentially complex as the eportfolio. Habron, et al., (2015) noted that, "unless specifically instructed to focus on personal development, students tend to focus on the content of the course and aspects directly related to the curriculum, and not the more relevant and beneficial aspects of ePortfolios that are consistently lauded (p. 5)."

## Conclusion

Technological advances are occurring at a rate unseen in human history. Students exiting high schools and colleges need to bring a wide variety of skills into the workplace. A critically important skill is the ability for workers to problem-solve. Children are naturally curious about their surroundings, each other, the world, and beyond. Educators have a unique responsibility to expand, while at the same time ground, this curiosity by developing activities that foster learning of various concepts, ideas, and ultimately prepare students to apply these experiences in real-world situations. This is important to remember, as according to Maida (2011), "Through an amalgam of knowledge, skills, teamwork, and communication, project-based learning helps to develop habits of mind associated with personal and occupational success in the global economy (p. 6)." This form of learning contains elements that form the basis of a "good job," which, according to (Crawford 2010) "requires a field of action where you can put your best capacities to work and see an effect in the world (p. 41)." If the United States is to remain competitive across global markets, we must be vigilant in developing student problem-solving skills. The workplace will demand they bring those skills, students should expect to be taught those skills, and we as educators must be committed to embedding those skills in our students to best prepare them for the future.

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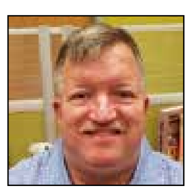

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