Integrated STEM Education through Project-Based Learning

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Abstract

Current research in project-based learning demonstrates that projects can increase student interest in science, technology, engineering, and math (STEM) because they involve students in solving authentic problems, working with others, and building real solutions (artifacts) (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005). Through an integrated approach to STEM education focused on real-world, authentic problems, students learn to reflect on the problem-solving process. Research tells us that students learn best when encouraged to construct their own knowledge of the world around them (Satchwell & Loepp, 2002). It is through integrated STEM projects that this type of learning can occur.

It is critical to pay attention to the extent of teacher knowledge and to support teachers throughout the project process in order for students to fully engage in the project topic (Satchwell & Loepp, 2002). This paper outlines the research underlying successful project-based STEM education and refers educators to a unique curriculum that supports teachers to implement a project that encourages students to solve problems in science, technology, engineering, and math (STEM) fields.

About Diana Laboy-Rush

Diana Laboy-Rush is an electrical engineer and a former math teacher, with a passion for exposing children of all ages to the possibilities of STEM. In 2007, she founded Portland Wiz Kids, a company that offers technology and engineering programs for elementary and middle-school students in a variety of school and enrichment settings. She joined Learning.com in 2009 as manager of its STEM programs, supporting educators to integrate STEM instruction into the classroom.
Math and Science Education Crisis

There is a crisis in American education today; too few students are graduating from high school fully prepared to begin a career or a college degree program (Diaz & King, 2007). Policymakers and education reform proponents are raising a call for students to learn complex, cognitive, social and communication skills to develop “habits of mind” – often referred to as 21st century skills. Students need to practice solving problems and making informed decisions, rather than merely warehousing collections of facts (Kolodner, et al., 2003).

Too often science education fails to engage student interests and is separate from their everyday experiences. Curriculum and education reform efforts suggest that when students “do science” they gain knowledge and skills that are transferrable to future problems and that help prepare them to approach college and career with the tools to succeed (Diaz & King, 2007). Research tells us that students learn best when encouraged to construct their own knowledge of the world around them (Satchwell & Loepp, 2002). It is through integrated STEM projects that this type of learning can occur.

Integrated STEM Education

Integrated instruction is any program in which there is an explicit assimilation of concepts from more than one discipline (Satchwell & Loepp, 2002). Integrated STEM education programs apply equal attention to the standards and objectives of two or more of the STEM fields – Science, Technology, Engineering and Math. There are myriad ways that a school or class can approach improving math and science education, but too often educators address the topics in silos, separate from any other subjects. When teachers expose students early to opportunities to learn math and science in interactive environments that develop communication and collaboration skills, students are more confident and competent in these subjects. This not only makes higher education more attainable for students, but also contributes to a well-prepared society.

In nearly every model of effective STEM integration, the goal and intent is to provide students with the opportunity to construct new knowledge and problem-solving skills through the process of designing artifacts (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naaman, 2005). They accomplish this through a series of open-ended, hands-on activities related to a thematic topic that addresses important concepts related to STEM disciplines (Satchwell & Loepp, 2002). Central to this process is involving students in defining and optimizing a solution for a real-world authentic problem.
Scientists and engineers approach problem solving with a goal of optimizing a solution to a problem, as opposed to proving that a problem is solved. Science curricula receive criticism because they do not provide students with experience in real-world problems, or include scenarios in which decisions are not clear cut and in which requirements conflict. These math and science curricula focus on well-defined problems in which the answer is known, there is only one solution, and the focus is on teaching students to get to the right answer (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005). In contrast, real-world problems are ill defined, and without one right answer. Through an integrated approach to STEM education, focused on real-world, authentic problems, students learn to reflect on the process they take in problem solving and retain the knowledge and skills they gain. Through explanation of hypothesis and ideas, they make connections between problem-solving goals and the processes to achieve those goals (Kolodner, et al., 2003).

Most often, educators develop integrated STEM programs around shared themes they base on national standards, such as the National Council of Teachers of Mathematics (NCTM) Focal Points, the National Science and Engineering Standards (NSES) by the National Research Council (NRC), the Technology Literacy Standards from the International Technology and Engineering Education Association (ITEEA) and the National Association of Educational Progress (NAEP). The most effective programs contain themes with a high potential for student interest, authentic problem solving, and rich, standards-based content in STEM (Satchwell & Loepp, 2002).

**Integrating STEM Education through Project-Based Learning**

Everyone naturally engages in problem solving. We all use the tools and materials available to us to adapt the environment to meet our needs. The ability to solve problems comes naturally to most. The project approach to STEM, or “learning by doing,” is grounded in constructivist theory (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005) that is shown to improve student achievement in higher-level cognitive tasks, such as scientific processes and mathematic problem solving (Satchwell & Loepp, 2002).

There are multiple research-based approaches to integrated STEM education – e.g., Design-Based Science (DBS) (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005), Math Out of the Box™ (Diaz & King, 2007), Learning by Design™ (LBD) (Kolodner, et al., 2003), Integrated Mathematics, Science, and Technology (IMaST) (Satchwell & Loepp, 2002), among others – all of which incorporate a process of inquiry-based activities that encourage students to contextualize the project with respect to existing knowledge and experience, and to communicate what they learned as a result. Generally, each program leads students through a four- or five-step process, with each step accomplishing a specific process-based objective. The following is a project-based learning process compiled from various project-based, integrated STEM programs that were evaluated and proven to be effective STEM education programs.
Reflection
The purpose of the first stage is to ground the student in the problem’s context and to provide inspiration for things the student can immediately begin to investigate (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005). This phase is also intended to connect what is known and what needs to be learned (Diaz & King, 2007).

Research
The second stage can take the form of student research, teacher-led lessons in science, selected readings, or other methods to gather relevant information and sources (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005). Much learning happens during this stage, in which students progress from concrete to abstract understanding of the problem (Diaz & King, 2007). During the research phase teachers often lead discussions to determine whether students are developing appropriate conceptual understanding of the project and its relevant concepts (Satchwell & Loepp, 2002).

Discovery
The discovery stage generally involves bridging the research and information that is known with the project’s requirements. This step is when students begin to take ownership of the learning process and determine what is still unknown (Satchwell & Loepp, 2002). Some models of STEM projects break students into small working groups to present possible solutions to the problem, to collaborate with fellow students, and to build on the strengths of their peers (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005). Other models use this step to develop the students’ ability to reflect on the “habits of mind” that the process is designed to build (Diaz & King, 2007).

Application
In the application stage the goal is to model a solution that sufficiently solves the problem. In some cases, students test the model against requirements, the results of which direct the students to repeat a previous step (Diaz & King, 2007). In other models, this stage extends the learning to contexts beyond STEM or to enable connections between the STEM disciplines (Satchwell & Loepp, 2002).

Communication
The final stage in any project is presenting the model and solution to peers and community. This is a critical step in the learning process because of the desire to develop both communication and collaboration skills and the ability to accept and implement constructive feedback (Diaz & King, 2007). Often, reviewers score authentic (rubric) assessments based on completion of this final step (Satchwell & Loepp, 2002).
Characteristics of Effective STEM Programs

Researchers on the Illinois State University’s Integrated Mathematics, Science, and Technology project (Diaz & King, 2007) found five characteristics for an inquiry-based curriculum to effectively promote STEM faculties. First, students get a variety and choice of learning tasks to involve them in the learning process and increase their motivation to complete the project. Second, they receive explicit communications and explanations to curtail any ambiguity caused by a problem’s open-endedness. Third, they have opportunities to model solutions, practice solving problems, and receive constructive feedback on high-level tasks from peers and coaches. Fourth, they engage in a student-centered instructional environment that focuses on the interests and needs of the individual learners. And fifth, each learner receives support for their individual learning needs and levels of development, from the high achievers to the struggling learners.

Challenges to Effective STEM Programs

Several challenges to successfully implementing integrated STEM education programs can be overcome with specific attention to the program’s design. There are, of course, the obvious challenges, including additional preparation time for teachers, the need for additional materials and resources, and the inventory storage, which, on the surface, may seem insurmountable. With a supportive administration and collaborative team approach, these challenges are manageable.

What is not as obvious, however, is how to address teacher attitudes toward several shifts in teaching practice. Authentic assessments can be subjective, which is often a new approach for teachers who are most comfortable determining grades based on objective tests and worksheets. Additionally, in integrated programs, teachers find themselves forced to learn new content, material that likely does not come easily to them. Evaluation studies of existing programs found that the teachers’ collective attitude toward implementing the program had a direct impact on student learning. These challenges can be mitigated through supportive administration, continuous staff development, and consultants who focus on the specific needs of teachers transitioning to a new way of teaching (Satchwell & Loepp, 2002). One practice is for teachers to experience a new inquiry-based STEM program as a learner before they are expected to support it as a teacher. Leading teachers through the student materials as a teacher development strategy goes a long way toward preparing and motivating teachers to embrace the pedagogical approach (Diaz & King, 2007).
Imagine Mars: Example of Integrated STEM Project

The Imagine Mars Project, by Learning.com, is a cross-curricular, integrated STEM curriculum that guides students in grades 3-8 to conceive, develop, and create a model community on Mars. The unit consists of five steps, each laying the foundation for the next. Following is a summary of the general intent of each step and how this project-based learning model integrates multiple disciplines.

Reflect
This step asks students to explore what they value about their own communities. To create a vibrant community on Mars, it helps to know what works right here on Earth. Students investigate what people like and dislike about their community. They learn how communities deal with challenges. And they learn how communities provide essential services. This step is the foundation of Imagine Mars. The project prompts students to think about this step as background rather than a blueprint for the Mars community they will design. All good engineers build on the successes of their predecessors. Students can think of this Reflect step as “doing their homework” to prepare for subsequent steps in Imagine Mars.

Imagine
Having researched what makes a good community on Earth, students envision a new community on Mars. There’s a lot to consider. What will they need to survive on the Red Planet and how will life be different there than on Earth? What will people in the community do? How will they work together? How much “stuff” can people take along? This step is preliminary brainstorming for the Discover step, in which students find concrete answers to many of the challenges people will face journeying to Mars. To help them begin to sort through the many questions and challenges, they examine expeditions of past explorers, look at programs designed to simulate conditions on another planet, and think about their community’s identity and purpose.

Discover
In this step, students get into the meat of what living and working on Mars will be like. They immerse themselves in all things Martian and examine how things such as communicating, traveling, getting essential supplies, and staying healthy will be different on the Red Planet than on Earth. They use factual data gathered in numerous space missions to help them understand the realities of being on Mars. Information gathered in this step will be crucial in the Create step, in which students build their model community.

Create
In this step, students build their community models. They use all the information gathered in the previous three steps to fabricate a model that represents not only how people will live on Mars, but also the community’s important cultural aspects. Students need to keep in mind that they are designing models to share with others in their school, community, or more widely. All aspects of STEM come into play in this step, and students also use technology to create 3-D models of their community.
Share
It’s time for students to share the fruits of their labor in this final step of Imagine Mars. Students should be intimately familiar with the challenges to living on Mars, and they also know about solutions that can make it possible. They’ve created a showcase of their Mars community in their models. Now, like any good scientist, engineer or mathematician, they need to share their findings with others. The purpose is two-fold: to explain how such an endeavor might be possible scientifically and realistically, and to respond to questions others may have about it. Students are now the experts, and they’ll get to show off their acumen as they present their community models to fellow students, parents, the community, and others.

Advantages of Project-Based STEM Integration

Transfer of Knowledge and Skills to Real-World Problems
Learning occurs best when students engage in finding real solutions to real-world problems. If knowledge and skills being taught are supportive of problem-solving efforts outside of the classroom then the goal of developing 21st century skills has been met (Fortus, Krajcikb, Dershimerb, Marx, & Mamlok-Naamand, 2005). When teachers introduce student to information, knowledge and skills in the context of problem solving rather than simply as facts, they are much more likely to retain and apply them to problems in new situations in the future.

Increased Motivation for Learning
Much can be said for instructional activities that motivate students to want to learn. According to Piaget, spontaneous motivation comes from developing mental abilities. When abilities are maturing, students will seek out stimuli to nourish their abilities (Elkind, 1999). By their nature, integrated STEM projects encourage students’ imagination and curiosity, thereby increasing their motivation to learn.

Improved Math and Science Test Scores
While not the most cited benefit from implementing STEM-based projects, it is important to note that several studies document an impact on student achievement. Specifically, the IMaST research team found that students who participated in the program saw an increase in scores in higher-level mathematical problem solving and scientific process skills (Satchwell & Loepp, 2002).

Conclusion
Teachers face enormous challenges to support students to begin a career or a college degree program, particularly in the STEM fields of science, technology, engineering and math. Teachers can successfully implement STEM education when they are supported with programs that are based on the best practices for program design. Project-based learning meets this need, and provides the roadmap for teachers to adopt a successful approach. Imagine Mars is an example of project-based learning that integrates STEM. This project exemplifies the benefits of project-based learning to enable students to transfer their knowledge and skills to real-world problems, to be motivated to learn, and to improve their math and science scores.
References


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