Key Ideas to Consider when Implementing STEM

Barbara M. Martin*, Anni Reinking

Abstract

This article provides strategies for how to successfully integrate STEM (science, technology, engineering, and mathematics) concepts. Research-based instructional strategies are introduced and described. A problem focused on constructing a bridge that supports five apples is used as an example to illustrate the instructional strategies. The strategies are divided into three themes with multiple subthemes. The themes are classroom environment, evaluation, and purposeful teaching.

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Students of the current generation are growing up in a time when problem solving, team building, and other 21st century skills are an important piece of their education (Puccio, Mance & Murdock, 2010; Trilling & Fadel, 2009). One way educators can ensure that students are prepared for their future careers and interactions is through the use of STEM in classrooms. “STEM is a curriculum based on the idea of educating students in four specific disciplines—science, technology, engineering, and mathematics—in an interdisciplinary and applied approach…. STEM integrates [the four disciplines] into a cohesive learning paradigm based on real-world applications” (Hom, 2014, para. 1). The 2010 President’s Council of Advisors on Science and Technology indicated that developing individuals with strong STEM backgrounds is needed in order for the United States to be a competitive country internationally (Holdren, Lander & Varmus, 2010).

This article will focus on implementation strategies in elementary classrooms. The ideas outlined in this article are practical suggestions based on educational theory and research. They are divided into three themes, each with subthemes. The three themes are classroom environment, evaluation, and purposeful teaching. After each theme is described, its subthemes will be introduced and described. The article will use one specific lesson example—challenging students to build a bridge to support five apples—as the three themes are explored. This lesson can be varied in many ways depending on the available materials and the grade level. Teachers, specifically elementary teachers, can use these ideas as a way to start or enhance the integration of STEM topics in their classrooms.

1. Classroom Environment

A welcoming classroom environment is essential to how students learn, grow, and develop socially and academically. The subthemes for this section focus on how a classroom teacher can create a welcoming environment where students feel free to question and learn about STEM-related concepts and applications, as in our bridge construction example.

To begin with, a classroom that is STEM supportive should be a safe environment that encourages questioning and open-mindedness. For example, as students contemplate and discuss the construction of a sturdy bridge, it is important to keep in mind strategies to encourage problem solving and inquiry. Educators should provide problems with multiple entry points, let students discuss and try various ways to solve the problem, and introduce open-
ended questions that promote critical thinking, rather than just yes or no questions. Examples of critical-thinking questions for the bridge construction lesson could include the following:

1. How did you decide on the material for the bridge you built? Why does it matter?

2. What questions do engineers need to ask themselves when building bridges?

The use of critical-thinking questions encourages inquiry-based thinking. In an inquiry-based classroom, the teacher’s role becomes less focused on direct instruction and more concentrated on modeling, guiding, facilitating, and continually assessing student work. Teachers in inquiry-based classrooms constantly adjust levels of instruction based on information gathered by assessment, whether informal or formal (Ash & Kluger-Bell 1999).

One way educators can encourage problem solving and inquiry is through the use of varied questioning techniques that align with the students’ levels of development with respect to STEM topics. This requires the teacher to play an active role in the STEM learning process and evaluate students’ understandings as they progress deeper into the knowledge base. Varied questioning techniques should move from lower-level to higher-level inquiries that require students to apply new knowledge (Vygotsky 1980). One way to implement varying levels of questioning is the use of Bloom’s Taxonomy (Bloom, Engelhart, Furst, Hill & Krathwohl, 1956). Questions or directions associated to the bridge activity could begin at a lower level, such as, “Label the parts of a bridge.” The questions could then become harder, finalizing at the top level, such as, “After researching and experimenting, construct a bridge that could survive holding up five apples.”

By encouraging students to question and problem solve, educators develop a classroom environment that is essential to the integration of STEM: a learner-centered, student-choice environment. Allowing students to choose the process, content, or product they would like to work with provides ownership and motivates learners to take an active role in their learning. In learner-centered classrooms, students feel accepted and supported, build a sense of ownership over their learning, and are more likely to be involved and willing to learn (National Research Council, 2000; Cornelius-White & Harbaugh 2009; McCombs & Whisler 1997; Watson & Reigeluth 2008). Using our bridge activity, student choice could be included in many ways throughout the unit. For example, students could explore different construction materials to use, or choose from among several resources while researching bridge design. Students could also have the choice of how to present their findings: for example, they could create a video of their experience building the bridge, a website to present their journey and findings, or a poster to show their process.

Cooperative learning is another way to provide a learner-centered environment. Balkcom (1992) defined cooperative learning as a teaching strategy in which small teams use a variety of learning activities to improve their understanding of a subject. When students work in a cooperative learning group, they are learning, communicating, and building on each other’s strengths, while helping each other improve areas of weakness. As part of the cooperative learning environment, students are able to foster long-term skill development. These skills, in turn, impact how students learn going forward; such as building relationships, developing emotional control, and practicing social skills (Elias, Wang, Weissberg, Zins & Walberg 2002).

Using the bridge example, students could work in collaborative teams to address the open-ended prompt, “Build a bridge, using only the materials provided, that could support the weight of five apples.” These teams would then be required to collaborate, communicate, use higher-order thinking skills, and enhance each other’s individual abilities to work together to solve the posed problem.

Learner-centered, cooperative learning classrooms also support creativity. Simply put by Ruppert (2010), “The arts—both as a standalone and an integrated curriculum—must

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be an integral part of the 21st century education if our students are going to succeed in a global economy” (p. 2). Twenty-first century jobs encourage creative thinking and novel ideas; therefore, students in today’s classrooms need to be allowed to explore their creativity within curricular constructs. Students should be given problems that allow open-ended, real-world applications of STEM concepts (this will be discussed under purposeful teaching) and that encourage creative and innovative approaches to problem solving.

The ability to be creative in a student-centered classroom allows students to explore. Exploration is another important piece of STEM integration in elementary schools. According to the National Research Council's report [2012], “Effective STEM instruction capitalizes on students’ early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest” (p.18). Relating this concept back to the bridge activity, many students have exposure to bridges in their communities; therefore, exploring the importance and construction of a sturdy bridge relates to prior knowledge and allows students to explore the community around them.

Encouraging students to explore, be creative, and engage in a learner-centered classroom not only creates a positive classroom environment, but also lends itself to differentiation. For students to maximize learning potential, teachers should consider proactively planning the classroom environment to meet the needs of various types of learners. One step in this process is to fully understand student and learner profiles, including students’ prior knowledge, previous learning experiences, social preferences, learning styles, and curriculum interests. When done thoughtfully and thoroughly, differentiation creates a classroom environment that meets the needs of all learners.

2. Evaluation

As with any lesson, it is best practice for STEM lessons to be based in standards and have evaluations that align with objectives. Teachers should adhere to and align student assignments and evaluations to the Next Generation Science Standards (NGSS Lead States 2013) and the Common Core State Standards (CCSSI (Common Core State Standards Initiative) 2010) for Mathematics. Also, the Illinois State Board of Education Social/Emotional Learning Standards (Illinois State Board of Education 2010) and International Society of Technology in Education National Educational Technology Standards (International Society for Technology in Education (ISTE) 2000) have become increasingly vital to consider. These foundational standards are in place to guide curriculum decisions when planning developmentally-appropriate instruction. In fact, some evidence suggests that adopting rigorous standards, aligning curriculum, and assessing those standards can lead to gains in student achievement (Marzano & Toth 2014). For the bridge-building example, some of the relevant standards from the Next Generation Science Standards are K–2–ETS1–1 or 2, which focus on engineering, making observations, and sketching a model. Additionally, technology standards might include how to use technology as a research tool or how to problem-solve and make decisions.

Evaluations are important to STEM integration because they provide a common language and set of expectations. Specifically, rubrics can be used for evaluation, self-reflection, and peer evaluation. Rubrics can be used as a way to provide a roadmap for groups or individuals to work towards a goal. Rubrics associated with STEM lessons should include goals of collaboration, team building, problem solving, and the use of knowledge gained about the topics covered in STEM. Figure 1 shows an example of a STEM rubric.

Rubrics are great ways for students to gauge their own work. Through this process, students are able to develop the lifelong practice of self-
Feedback: Peer and Self-Reflection for STEM Projects

(Mark your feedback on the continuum.)

<table>
<thead>
<tr>
<th>Exploration:</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigating something new to learn about it</td>
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| Collaboration: | Working with group members to create or discover a shared goal |
| Cooperation: | Sharing information learned and resources gathered |
| Problem-Solving: | Finding solutions to difficult scenarios/problems/questions |

What was your personal learning experience? (Teacher notes: This portion of the rubric needs to be progressively taught throughout the school year in order to cultivate self-reflection techniques. In this section students may include reflections on the trials and failed attempts, thinking processes or overall reflections.)

Figure 1: Feedback: Peer and self-reflection for STEM projects

reflection. Self-reflection and self-assessment can be completed by recording thoughts and reflections, or by assessing one’s own work using a rubric. Students who are able to reflect on their experiences and personal solutions engage in metacognition. If students know and understand their own learning processes, they are better able to achieve learning objectives (Stoll, Fink & Earl, 2003).

While self-reflection is a great tool for students to learn and personally grow, the concept of peer evaluation or feedback is also an important strategy. Peer reviews are essentially the evaluation of work by a classmate. The addition of peer evaluation to the STEM process improves problem solving, critical critiquing strategies, and collaboration. When an environment in a classroom is built around cooperation, collaboration, and the joy of seeing peer success, the peer evaluation process will be one of learning and constructive feedback.

3. Purposeful Teaching

The final theme, purposeful teaching, focuses on how educators can make and create meaningful connections for students when integrating STEM concepts into the curriculum. For the purpose of this article, the authors are using the term “purposeful teaching” to mean how teachers can proactively plan for opportunities that encourage students to build STEM knowledge that is relevant, significant, and impactful.

When considering meaningful connections and
how to integrate STEM, it is important for educators and students to keep an open mind. The ability to be open-minded allows students to engage in productive conversations around solutions. In our example of building a bridge, teachers would pose an open-ended question and allow students time to explore, discuss, and research the topic.

Once educators are open to the explorative nature of STEM integration, it is important to consider the hands-on possibilities of STEM lessons. The National Research Council’s Framework for K–12 Science Education (2012) articulates and discusses how engineering can play the role of a mechanism by which students can learn meaningful scientific concepts. Furthermore, it has long been recognized that experiential, hands-on education provides motivation and inspiration for learning new material by providing real-world meaning to otherwise abstract knowledge (Mataric, Koenig & Feil-Seifer, 2007). Essentially, all learning using STEM is related back to hands-on experiences.

Incorporating hands-on experiences supports the idea of using real-world problems when implementing/planning STEM curriculum. The Common Core Mathematics Standards (2010) focus on the use of real-world problems to concretely teach ideas and concepts. However, the movement in education to incorporate real-world and relatable problems to solve extends beyond the core content area of mathematics. According to Tsupros, Kohler & Hallinen (2009), STEM integration can provide students with some of the best opportunities to experience learning in the real-world, rather than learning STEM subjects in isolation. There is a natural overlap between science, technology, engineering, and math concepts that provide a perfect opportunity for students to apply their knowledge to real-world situations, which strengthens their understanding and motivation to learn, as described earlier. Relating back to the bridge example, students could be given the example of a community that needs to replace a bridge and is taking applications for structural ideas. Cooperative learning groups are then tasked with completing the application for best bridge design that can support five apples. Other examples of real-world problems are described as part of the discussion of service learning partnerships with community organizations.

While hands-on learning and real-world application are important, purposeful teaching can also be achieved through well-designed assignments that help students recognize cross-curricular ties between and among all subjects. Clearly communicating and exploring how STEM concepts rely on and enhance each other is vital to students’ full development of subject knowledge. Specifically, students and educators who recognize the importance of cross-curricular ties are able to develop deep vertical knowledge, rather than attempting to understand a larger amount of surface-level information, also referred to as horizontal knowledge. Kelly (2013) suggests that curriculum should include space for learning outside the academic boundaries so that children make connections between different disciplines. Using our bridge and apple example, students might examine the technology used by engineers and architects to plan and build a bridge that is sturdy. Students also might explore the math needed to determine the weight or height of the five apples.

Additionally, students can incorporate language arts by writing hypotheses or fine arts by drawing and labeling a picture of the proposed bridge. It is important to help students understand that science and math do not happen in isolation, just as real-world problems do not happen in isolation. Interest in STEM areas can be fostered when students begin to understand that all knowledge and learning is intertwined (Goldman & Pellegrino, 2015).

Purposeful teaching can be met through cross-curricular teaching and tying the knowledge to real-world problems, while also incorporating college and career readiness in the classroom. College and career readiness is an increasingly important concept in the field of education and means that high school graduates have the knowledge and skills in English and mathematics necessary to qualify for and succeed in college.
and/or the workforce. However, college and career readiness does not start and end at the high school level. It begins in the elementary grades. Furthermore, it means that students are ready to work in the real world, which is a world of the 3Cs: collaboration, communication, and cooperation (Fuks, Raposo, Gerosa, Pimental, Pimental, Mariano & Mariano, 2008).

A great way to incorporate real-world scenarios and problems is through the addition of service learning partnerships that integrate STEM curriculum. Service learning “combines learning goals and community service in ways that can enhance both student growth and the common good” (Bandy, 2016, para. 1). Integrating service learning projects increases students’ social-emotional capacity, while also developing a sense of what needs are in the community, how to collaborate with community organizations, and the processes of urban planning (Billig, 2000). The use of service learning projects in collaboration with STEM curriculum can take many forms. Examples of service learning and STEM integration can be accomplished through a classroom field trip to a construction site or visiting an engineer about bridge design, both of which could be great enrichment experiences for elementary children. Overall, service learning partnerships could provide students with a knowledge of how community members can contribute and use their education to solve typical, real-world, hands-on problems.

Finally, after all of the learning, problem solving, team building, cooperation, collaboration, cross-curricular planning, and questioning, it is important to show off the hard work of the students. Inviting families, parents, and community members in for a showcase night creates a way for students to display their work and show their families the learning that occurred over a span of time. The showcase night boosts students’ self-esteem, provides an avenue for sharing STEM curriculum, and involves families and community members in the life of the school and classroom.

4. Conclusion

STEM is an important aspect of the education field. Through incorporating STEM curriculum, students become holistic learners; they become scientists, engineers, and mathematicians. Students are able to work collaboratively with a goal in mind and reflect and provide constructive feedback. Teachers also benefit from the experience of STEM integration in an elementary classroom. Teachers become creators with the students, observers, reflectors, and guides in a student-centered classroom. As STEM curriculum continues to flourish in education, students benefit and are becoming prepared to live, work, and function in a future world.

References


