Using Project-Based Learning to Enhance STEM Education in Elementary Science Classrooms

Kaela Bilski

Abstract: As the demand for highly qualified workers continues to rise in STEM career fields, US schools are responding by placing a greater emphasis on STEM education with the goal of improving both student achievement and interest in these areas. Despite the trend toward increased STEM initiatives in schools, there has been limited research into best teaching practices for STEM education, and many teachers express discomfort with both STEM content and pedagogy. One approach to STEM education that research has shown to be highly effective is Project-Based Learning (PBL). This article explores the impact of PBL and outlines a pedagogical framework for implementing PBL in the science classroom to support student achievement and improve student and teacher attitudes toward STEM fields.

Introduction

Over recent years, the demand for workers in the fields of science, technology, engineering, and mathematics (STEM) in the United States has risen drastically. According to the Bureau of Labor Statistics, the number of STEM careers is expected to grow by 13% between 2012 and 2022, in comparison to an 11% growth rate for non-STEM careers (Vilorio, 2014). As of 2016, the ratio of the number of available STEM jobs to unemployed STEM workers was 13:1—leaving approximately three million jobs unfulfilled (New American Economy, 2017).

The projected increase in STEM jobs coupled with the current deficit in highly qualified STEM workers has led to an emphasis on STEM education in US schools, with the goal of improving both student achievement and interest in STEM fields. Yet despite the trend toward increased STEM initiatives, there has been limited research into best teaching practices for STEM education, and many teachers express discomfort with both STEM content and pedagogy. One approach to STEM education that is both supported by research and also becoming increasingly popular is Project-Based Learning (PBL). Research has shown project-based STEM learning is an effective pedagogy approach to STEM education. When incorporated effectively in the classroom, it has a positive effect on student achievement and motivation.

Historically, STEM has referred to any of the four STEM disciplines as an isolated unit, most typically science (English, 2017; Han, Capraro, & Capraro, 2014). More recently, the term has also been applied to describe the teaching of two or more of the content areas simultaneously. In either case, contemporary science teachers are regularly charged with incorporating STEM into their curriculum. For this reason, while PBL can be applied in many different classroom contexts, this paper will examine the ways in which this approach can be implemented specifically in the science classroom.

Why a project-based approach to STEM education?

Though research into the impact of PBL on STEM education is limited, the research to date has shown that PBL can be used to improve student achievement in STEM content areas as well as student attitudes toward STEM. When students engage in open-ended projects, they demonstrate deeper growth in their understanding and appreciation of the content (English, 2017). This is particularly important if the goal of increasing the number of students pursuing STEM careers is to be met. When students appreciate the topic and are successful in the classroom, they may be more likely to pursue additional education or a career in the field.

Many studies have found that students' mastery of content knowledge increases when they are engaged in PBL. Cwikla, Milroy, Reider, and Skelton (2014) found that after completing a collaborative research project titled Pioneering Mars, 100% of high school students showed an increase in content knowledge immediately following the project and 70% demonstrated an increase in subject knowledge during a follow-up assessment several months later. Additionally, PBL has been shown to be an effective tool for closing the achievement gap. Though STEM-centered PBL has a positive effect on student achievement for students at all learning levels, low-achieving students often benefit more than their higher-achieving peers, as evidenced by the largest growth in content knowledge gained (Han et al., 2014).

In addition to increasing student achievement, PBL has also been correlated to improved attitudes toward content. Following the Pioneering Mars project, Cwikla and colleagues (2014) found that 64% of students felt the project provided them greater insight into STEM fields, and 85% of students indicated they were interested in pursuing STEM careers. Students in this study also expressed positive feelings about the real-world implications for the project, because they believed that it was meaningful, and could contribute to later scientific breakthroughs. Likewise, middle school students who participated in the project-based See Blue STEM camp indicated a 3.1% increase in interest in STEM careers, resulting in approximately 80% of participants being interested in pursuing STEM careers (Mohr-Schroeder et al., 2014).

A Pedagogical Framework

Despite the popularity and effectiveness of the project-based approach to STEM education, there remains a lack of consensus about what constitutes effective STEM educational practices, or effective PBL STEM practices. This has led to a shortage of highly qualified STEM teachers (Schmidt & Fulton, 2015). Even in instances where STEM is taught, several key principles of project-based STEM education are regularly not addressed, indicating students may not be experiencing all the benefits of this approach (Hall & Miro, 2016). In response to this problem, many research studies have attempted to more clearly define PBL by identifying key components and guiding principles. Though the language and minor details of the current research varies, there are several overarching themes in the components of effective PBL for STEM education. Key components of effective project-based STEM learning include authentic problem-solving, experiential learning tasks, engagement in higher-order thinking skills, cross-curricular integration, and collaboration and reflection.

Authentic Problem-Solving

The first step in designing a project for STEM instruction is to pose a question or problem to students. This can be done in one of two ways. The first is by beginning with an activity that requires minimal content and providing opportunities for students to generate questions and ideas (English, 2017). For example, when introducing a project about weather, the teacher may ask students to make observations about the weather over the course of several days in a journal along with any questions or ideas they have. This allows students to raise questions such as "Why is it always cloudy before it rains?" or make hypotheses like "The sun is hot because it is sunny on warm days." Students can then use these questions and ideas to design a project to help them answer or confirm them. The second strategy is for the teacher to pose a question or problem to students and encouraging them to think about ways to answer or solve the problem (Wan Husin et al., 2016). This promotes critical thinking strategies and engages students' creativity

When developing a question or problem, teachers should use authentic, real-world experiences. Cwikla and colleagues (2014) revealed the importance of using real-world experiences through their research on the use of PBL with high school students. As a result of the authenticity of the project, students showed increased gains in knowledge and skill acquisition; they commented on how the meaningful and hands-on nature of the project helped them remember the content more effectively (Cwikla et al., 2014). However, such "real-world" experiences may not always be feasible due to a lack of resources or funding, and there may also be an increased possibility of failure associated with the risks of real-world projects. In this case, "real-world" is better described as "realistic" (Warin, Talbi, Kolski, & Hoogstoel, 2016).

Experiential Learning Tasks

Learning tasks should engage students in meaningful, hands-on opportunities to answer questions posed by the teacher. This idea is rooted in the belief that students construct meaning through interactions with their environment (Liu, Lou, Shih, Meng, & Lee, 2010). Rather than the teacher transmitting knowledge to students, students create knowledge for themselves as they design and implement an investigation, and they practice using real skills and tools to solve problems (Hall & Miro, 2016; Schmidt & Fulton, 2015). This facilitates not only students' understanding of the content, but also their appreciation of that content (English, 2017). When students are actively involved and have a voice in designing learning experiences, they make connections between the content and their background knowledge, often using experimentation and questioning to fill gaps in their understanding (Karchmer-Klein & Layton, 2006). This moves students from being receptive learners to active learners.

Higher-Order Thinking Skills

When students become active learners, they develop habits of mind associated with 21st century skills such as lifelong learning, civic responsibility, and personal or career success (Liu et al., 2010; Warin et al., 2016). In order to encourage the development of these skills, PBL must intentionally address all six levels of Bloom's Taxonomy. Engaging students in higher-order thinking skills, extends their thinking beyond simple knowledge and strategy application and shifts the focus of learning from rote memorization to the long-term development of cognitive skills (English, 2017; Schmidt & Fulton, 2015). In order to accomplish this, PBL should be focused on the process rather than the outcome (Schmidt & Fulton, 2015). Teachers should encourage students to think about the steps they are taking, why they are taking those steps, and should be considering their own understanding of the content throughout the process.

Cross-Curricular Integration

Building off the idea that projects should be authentic, integration of two or more subjects is vital to the success of PBL. In the real word, disciplines are not separated as they are in schools. Consider the development of a new pharmaceutical. When developing the drug, pharmaceutical scientists will use knowledge and skills in science to develop and test the drug, in mathematics to calculate chemical ingredients and analyze data, and in technology to synthesize the drug and collect data. The disciplines are not approached in isolation but rather woven together to contribute to the overall success of the development of the pharmaceutical. The objective of integrative STEM education is to prepare students for real-world problem solving and work in which cross-disciplinary approaches are being utilized (English, 2017).

STEM integration extends far beyond simply teaching two content areas simultaneously. The most common form of STEM integration is the utilization of one content area to support the learning objectives of another (English, 2017). For example, technology is often used to support learning objectives in science. It is important to note that incorporating one discipline simply for the sake of incorporation is not an integrated experience. Rather, true integration occurs when one discipline is a conduit for learning and students are acquiring knowledge about both disciplines. For example, by utilizing technological tools to complete an investigation, students acquire new technological literacies while simultaneously learning science content (Schmidt & Fulton, 2015).

Collaboration and Reflection

Additionally, the effective implementation of PBL creates positive communication and collaborative relationships among diverse groups of students and STEM professionals (Liu et al., 2010; Mohr-Schroeder et al., 2014). When students collaborate with STEM professionals who are experts in their fields, they gain insights into subjects that allow them to better construct ideas and increase their knowledge and skills. Collaboration with peers allows students to share their ideas and reflect upon their own understandings. When students share their learning with one another, they extend their learning within and beyond the classroom (English, 2017). And when students reflect upon and evaluate their results, they are able to find ways to improve their work (Kitagawa, Pombo, & Davis, 2018; Macalalag, Johnson, & Johnson, 2018; Schmidt & Fulton, 2015). By sharing with their peers, students are able to identify their own misunderstandings and areas for improvement.

PBL within the Science Classroom

Imagine a fourth-grade classroom in which the teacher implements PBL to facilitate learning about the interrelationships among and between biotic and abiotic factors in ecosystems. To begin the project, the class visits a local Metropark where they learn about the endangered Karner Blue Butterfly. Park rangers guide students on a hike and students use a field guide to help identify the species in egg, larvae, cocoon, and adult stages within the park. Once students identify the species, they use a journal to record observations of the various biotic and abiotic factors within the butterfly's habitat. Knowing that some biotic factors may not be immediately visible, the students use field guides and consult the park rangers to interpret evidence of other species (such as animal tracks) within the area.

Following their visit, students meet in small groups and discuss their findings. Several groups noticed that Karner Blue larvae are only observed on blue lupine plants and hypothesize that it must be food for the caterpillars. Once all groups have had a chance to share their findings, the teacher poses the question, "How can we use this information to help the Karner Blue Butterfly?" After careful consideration, students hypothesize that if they were to plant more blue lupine plants, the larvae would have enough food to grow.

Over the next several days, the students begin to plan experiments to determine ideal growing conditions for the lupine plants. As part of their planning, students conduct research online about recommended growing conditions for the plant and even video conference with a horticulturist from their local zoo to help answer questions about sun exposure, temperature requirements, soil type, pH, nitrogen and rainfall requirements. After several days, students believe they have identified ideal growing conditions and have formulated an experiment to confirm their hypothesis. Their teacher provides students with the necessary materials for conducting their experiments and the students carry out the experiments over the next two weeks.

Once tests are complete, the students use a map of the Metropark, their prior knowledge, and the findings of their experiments to identify six potential locations the plant could grow. The teacher arranges for the students to visit the park again and asks the park rangers to set out rain gauges in areas students plan to test. Two weeks later, students return to the Metropark and collect soil samples. Students record information about sun exposure, temperature, rainfall, and soil type upon collection to label the samples. Students also use pH gauges and nitrogen strips to test the pH and nitrogen of soil respectively.

The following day at school, the teacher shows students how to compile and analyze data in a cluster graph. Small groups work together to generate and analyze graphs, with each group focusing on one soil factor. Once complete, the groups share their findings and the class decides that the best area in which to plant the seeds is in a part of the park covered by pine forest.

A few weeks later, the class visits the Metropark once more to spread blue lupine seed in the area. After completing the project, students write a short essay about the experience and what they expect to happen. One student writes, "It was so cool to think all the tests we ran could actually help save the butterflies! I felt like a real scientist!"

In this project, we see how all the components of effective PBL come together. Students had worked together to answer a question about how relationships within an ecosystem can impact an individual species. In this case, the students had decided that increasing the food supply of the butterflies would help increase the number of individual butterflies. Since the students were working with the Metropark, the project is authentic. Throughout the entire project, students were engaged in hands-on experiences and high-order thinking skills as they formulated hypotheses, ran tests, and drew conclusions based on evidence. Collaboration occurred in small peer groups, whole class discussion, and with experts within the field. Though the primary focus discipline of the project was science, students also learned technological skills through their use of technology to conduct their tests. Mathematics was also integrated through the creation and interpretation of graphs to justify where the plants should be planted. Finally, students reflected on the experience and their understanding during the writing of their essays at the end.

Conclusion

In today's educational climate, despite extensive research into the benefits of project-based STEM education on student attitudes and achievement, little evidence exits that these strategies are being effectively implemented. The ambiguity surrounding what constitutes effective STEM and PBL practices, as well as a lack of teacher preparation has led to feelings of discomfort among teachers and left them hesitant or unable to provide such instruction. As the emphasis on STEM education continues to grow, educators will need to identify best practices for STEM education to help teachers feel more confident in providing instruction in STEM education. The objective of this manuscript was to clarify the components of effective PBL and discuss how they could be applied within elementary science classrooms to support STEM. Improving teacher understanding of how apply PBL effectively can help science educators effectively implement STEM education, and help them transform their students from receptive to active learners.

References

Cwikla, J., Milroy, S., Reider, D., & Skelton, T. (2014). Pioneering mars: Turning the red planet green with earth's smallest settlers. *The American Biology Teacher*, *76*(5), 300-305.

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education, 15*(S1), 5-24.

English, L. D., & King, D. T. (2015). STEM learning through engineering design: Fourth-grade students' investigations in aerospace. *International Journal of STEM Education, 2*(1), 1-18.

Hall, A., & Miro, D. (2016). A study of student engagement in project-based learning across multiple approaches to STEM education programs. *School Science and Mathematics, 116*(6), 310-319.

Han, S., Capraro, R., & Capraro, M. M. (2014). How science, technology, engineering, And mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education, 13*(5), 1089-1113.

Karchmer-Klein, R., & Layton, V. (2006). Literature-based collaborative internet projects in elementary classrooms. *Reading Research and Instruction, 45*(4), 261-294.

Kitagawa, L., Pombo, E., & Davis, T. (2018). Plastic pollution to solution. *Science and Children, 55*(07), 38-45.

Liu, Y., Lou, S., Shih, R., Meng, H., & Lee, C. (2010). A case study of online project-based learning: The beer king project. *International Journal of Technology in Teaching and Learning, 6*(1), 43-57.

Macalalag, J. A., Johnson, B., & Johnson, J. (2018). Engineering encounters: STEM-ify me: It's elementary! Designing butterfly wings. *Science and Children, 55*(09), 76-82.

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., Schooler, W, & Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences: See Blue STEM camp. S*chool Science and Mathematics, 114*(6), 291-301.

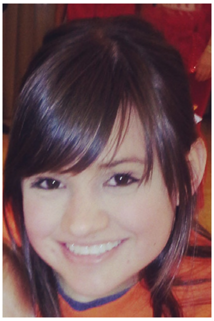
New American Economy. (2017, March). Sizing up the gap in our supply of STEM workers. Retrieved from https://research.newamericaneconomy.org/report/sizing-up-the-gap-in-our-supply-of-stem-workers/

Schmidt, M., & Fulton, L. (2015). Transforming a traditional inquiry-based science unit into a STEM unit for elementary pre-service teachers: A view from the trenches. *Journal of Science Education and Technology, 25*(2), 302-315.

Vilorio, D. (2014, Spring). STEM 101: Intro to tomorrow's jobs. *Occupational Outlook Quarterly*, 2-12. Retrieved from https://www.bls.gov/careeroutlook/2014/spring/art01.pdf

Wan Husin, W., Mohamad Arsad, N., Othman, O., Halim, L., Rasul, M. S., Osman, K., & Iksan, Z. (2016). Fostering students' 21st century skills through project oriented problem based learning (POPBL) in integrated STEM education program. Asia-Pacific Forum on Science Learning and Teaching, 17(1). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=ehh&AN=118111100&site=eds-live

Warin, B., Talbi, O., Kolski, C., & Hoogstoel, F. (2016). Multi-role project (MRP): A new Project-Based Learning method for STEM. *IEEE Transactions on Education, 59*(2), 137-146.



About the Author

Kaela Bilski received her B.S. in Education from Bowling Green State University and holds PK-5 licensure. She obtained a M.Ed. in Early Childhood Education from The University of Toledo and is completing a M.Ed. in Curriculum and Teaching. She currently develops project-based curriculum for the Toledo Zoo's school partnership programs.