Engineering Design Process: Across the Curriculum

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Introduction

Science, technology, engineering, and mathematics (STEM) have gained popularity in schools nationwide in recent decades. Engineering, one of the four components of STEM, is also starting to make its way into science standards. 41 states have included engineering in their academic standards, and the Next Generation Science Standards (NGSS) has included engineering design in their updated standards (NGSS Lead States, 2013; Moore et al., 2015). Our project focuses on how the Engineering Design Process (EDP) can be implemented as an instructional process outside of the traditional STEM setting. The EDP is the process of identifying a real-world problem, creating and testing solutions, and evaluating the end product (Gabel, 2021). It promotes resilience and teamwork, as students may need to revise their final product multiple times (teachengineering.org, n.d). Implementing EDP into the curriculum is a way to advocate for students as a wealth of research shows that engineering design can help educators meet the needs of diverse learners. In this paper, we will further explore the topic of the EDP, explain how we incorporated it into our project, and discuss what we learned through the research and development of our project.

Why is this theme/topic important to you and others in the education community?

Research comparing American students to those in other countries shows that the U.S. is falling behind in STEM education (Athanasia & Cota, 2022). In addition, the Pew Research Center gathered data showing that of scientists from the American Academy for the Advancement of Science (AAAS) who were polled about U.S. STEM education, only 16% would rank our STEM education as above average or the best in the world. Only 29% of the general public polled would rank American STEM education as above average or the best in the world (Pew Research Center, 2015). When combined with other issues in education, such as equity for all students, recent teacher shortages, and post-Covid learning loss, this presents a need for quality STEM instruction at all grade levels.

The recent introduction of the NextGen Science Standards (NGSS Lead States, 2013) indicates that there is an effort to create opportunities for students to solve complex, real-world problems in STEM classrooms. Former teaching paradigms in science, mathematics, and other K-12 classrooms emphasized the memorization of facts and solving problems with one correct answer. The NGSS, however, emphasizes that students should practice the skills that scientists and engineers use in their work such as making models, engaging in iterative design processes, and interpreting data (National Research Council, 2012; NGSS Lead States, 2013).

However, concerningly many teachers report feeling unprepared to teach engineering design despite agreeing with the benefits students may reap from such experiences (Banilower et al., 2013; Crismond & Adams, 2012; Hsu, Purzer, & Cardella, 2011). Professional development for teachers in instructional strategies to facilitate STEM learning and scaffold students in conducting engineering design challenges is needed to help increase teacher confidence and efficacy in planning and implementing the use of the EPD in K-12 STEM classrooms. Incorporating EDP challenges into a cross-curricular context can help teachers solve problems that plague STEM education, such as a shortage of instructional time, as well as provide relevant, real-world contexts for student problem solving.

Why did you decide to approach the theme/topic in the way that you did?

"In the past few decades, many promising educational reforms and innovations have failed because the programs needed to help teachers develop their capacity to employ those reforms and innovations” (Jong, 2021, p.81). One weakness for many students is the need for more stamina with problem-solving skills and their inability to grapple with productive failure.

We approached this deficit by teaching our teachers the EDP. This was the most effective way to get students thinking about solutions for real-world problems in a new way, while also meeting 21st-century job skills. “In line with the substantial interest in STEM (science, technology, engineering, and mathematics) education and the significant projects in STEM curriculum development worldwide, efforts should be made to increase the supply of STEM teachers through proper and effective teacher professional development” (Jong, M., Song, Y, et al. 2021. p.81).

We decided to have a professional development for teachers that would introduce them to the EDP through active learning and then have each discipline go to breakout sessions to get information specific to their field. The professional development then allows teachers to have planning time with their curriculum to find ways that they could incorporate the EDP. This is invaluable because they can work with other teachers in their discipline and have the presenters as well as other experienced STEM teachers there to help. As educators presenting information, we realize that teachers want information that can directly impact their teaching. They also want things that are ready to implement when they go back to their classrooms.

What were the opportunities and challenges involved in your project work?

The opportunities with this project are applicable to many different disciplines. It is intentionally designed to be utilized through many different classrooms. During this professional development, teachers from all disciplines will come together to learn about the EDP, and then work together by discipline to discuss with each other how they could use EDP in their classrooms, while STEM teachers will be dispersed in the groups as subject matter experts. By grouping together with other teachers in their disciplines, they would understand each other better and be able to support each other while also getting to know a few STEM teachers outside their department, building a bridge for future collaborations.

In this instance, the opportunities go hand in hand with the challenges. There aren't many resources developed to incorporate engineering with other subjects, nor is there much research evaluating the effectiveness of combining both. This challenge gives researchers an opportunity for a field to study at a level higher than elementary ages. This is important because not only can engineering help explain or retain content within other fields, but individuals more experienced in other fields can help those in engineering. "Solving engineering problems requires knowledge from a variety of domains and benefits from teams of individuals bringing multiple perspectives" (Hynes, M. & Swenson, J., 2013, p. 35).

What was/is/may be the impact of your project work?

Creating an EDP professional development for teachers of content outside of traditional STEM has shown to be necessary in today's classroom. As the pandemic forced education to move online, more tech savvy teaching became a necessity. As teacher's are re-learning and constantly adjusting how to teach to a generation of student's with even shorter attention spans, having an engaging, hands-on experience in classrooms is a task that many teachers are struggling with.

The EDP allows teachers to use real-life scenarios as their defined problem and gives students an opportunity to use information learned in school to solve the problem. As a result, teachers should see higher student engagement which lends itself directly to an increase in student learning. Alba and Fraumeni (2019) state “engagement isn’t just a reflection of success in school, but a contributor to it” (p. 1). According to Athanasia and Cota (2022) “the United States needs to reinvigorate its STEM (science, technology, engineering, mathematics) education system if it is to compete successfully in the 21st century.” Utilizing EDP skills in classes outside of STEM will assist in bringing formal learning full circle for students. Too often students view school as a multitude of disciplines that do not intersect, and teachers sometimes miss the opportunities to make cross-curricular connections for their students. The EDP requires students to utilize skills learned in other disciplines to successfully answer questions or solve problems. This directly impacts the quality of instruction for teachers by requiring the cross-curricular connections to happen more naturally. For example, utilizing EDP in a reading class has the potential to bring in science skills and knowledge. One of the main issues surrounding the incorporation of EDP in any classroom, especially those non-STEM disciplines, lies in the fact that many teachers feel unprepared to engage in EDP due to the novelty for some, and the simple uncertainty of student learning for others (Banilower et al., 2013; Crismond & Adams, 2012; Hsu, Purzer, & Cardella, 2011). Our professional development helps alleviate the tension of the unknown, while providing teachers a safe place to fail.

What were your main lessons learned from the project in terms of content and process (i.e., planning and implementation)?

Our group is composed of three science teachers, one experiential learning coordinator, and one special education teacher. In terms of planning, one of the main lessons learned was how much the little things matter to those who are less experienced with a science heavy concept. For example, when we created the agenda for the day, something small such as including the exact time frame for each segment was inherently understood among our group, but needed to be spelled out for those who are not consistently working from a “problem-solving” perspective. We also realized there were some things that were second nature for us, such as finding a science link with every aspect of teaching yet could prove to be major hurdles for teachers of non-science disciplines. That realization helped to give our project direction as we planned the “how” in implementation.

Our “why” for the project was simple. 21st century skills are essential to the future success of America on a competitive innovation stage and those skills need to be developed and fine-tuned throughout the duration of formal education. The “how” was more of a challenge as we struggled to find research on the implementation of the EDP into non-STEM core content classrooms. While this presented a challenge it also offered an opportunity for our group to learn and conduct research on how providing students with these 21st century skills in non-STEM disciplines impacts their future success.

In terms of implementation, our group is no stranger to the EDP and how it can be used as a best practice for both teaching and learning. With that, we determined the best way to get teachers to “buy-in” was to engage them in an experience that required the EDP to be utilized. After sharing our project with classmates, we learned that in presenting the EDP as a challenge versus simply talking about it, teachers were ready to give it a try almost immediately. This phase of implementation provides promise that our project is both on the right track and a necessity in today’s classroom.

What future actions can be taken or do you anticipate taking related to this theme/topic?

One aspect of this topic that can be further researched is the implementation of STEM and EDP in the younger grades. Hsu et al. (2011) found that many primary teachers were unfamiliar with how to teach design, engineering, and technology to elementary students and had little training or confidence in this area, despite many of the teachers agreeing that it was important. Sung & Kelley (2022) did a research study on the EDP with grades three through six and found that students of this age were still able to come up with diverse solutions in the EDP process, but it depended on many factors. They emphasized the importance of teaching EDP as a cyclical process and not a linear one. Although younger students may not have as many higher order thinking skills, they are still capable of participating in EDP and should be given more opportunities to do so. Further research on how we can successfully teach them fundamental skills needed for EDP will help them with EDP and STEM related skills in upper grades.

An area of EDP that we anticipate growth in is the solidification of assessment strategies. Since this process is open ended, assessment strategies can vary greatly. Although they include the terms engineering design in their standards, the NGSS does not have a clear evaluative process of engineering design, nor are there specific guidelines present on how to use EDP (Moore et al., 2015). The National Center for Engineering and Technology Education (2012) suggests selecting outcomes and using portfolios, design notebooks, and oral presentations along with a specific rubric to evaluate engineering design challenges. As more states begin to expand upon the engineering design process in their science standards, hopefully, STEM teachers will be given more direction on evaluating EDP with their students.

Throughout our project, we found little research regarding EDP and other school subjects. Incorporating music, art, language arts, and social studies with STEM can "further expand STEM into the meaningful, real-world context to both reinforce the integrated nature of learning while supporting the work of building students' access to 21st-century interdisciplinary themes and skills" (Du, et al., 2019, p. 106). If combining STEM with other subjects is successful, then it would be interesting to see the long-term impact of interdisciplinary EDP, as EDP is a crucial part of STEM.

Conclusion

The purpose of the professional development module we developed is to show teachers how to implement the EDP in classrooms in meaningful, cross-curricular contexts for the benefit of all learners. Furthermore, we hope that non-STEM teachers can find ways to confidently integrate EDP into their classrooms to challenge students to engage in open-ended problem solving and increase student motivation to learn about STEM disciplines and careers. Cross-curricular challenges can be developed to aid students in connecting STEM issues with other disciplines (such as social studies, the arts, and language arts); as well as reflect the nature of real-world problems. Providing an EDP in non-STEM disciplines illustrates the complexities that STEM professionals - as well as professionals from other disciplines - must navigate in solving such problems. The EDP quickly teaches students that problem solving is not always linear, as many believe, and can have many variations of the "correct" answer. Finally, incorporating EDP across the curriculum can help to facilitate collaborative experiences for both students *and* teachers which can improve motivation and satisfaction for both teaching and learning.

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