The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41238

Board 169: Purposefully Designing Integrated STEM Learning Experiences within Elementary Teacher Education (Work in Progress)

Dr. Ursula Nguyen, University of Nebraska, Lincoln

Dr. Ursula Nguyen is an Assistant Professor in Elementary Mathematics Education in the Department of Teaching, Learning & Teacher Education (TLTE) at the University of Nebraska-Lincoln. Dr. Nguyen's research broadly focuses on issues of equity in STEM education at the intersection of race/ethnicity and gender, which stems from her experiences as both an educator of STEM subjects and as a past engineering student.

Deepika Menon, University of Nebraska, Lincoln
Dr. Minji Jeon, University of Nebraska, Lincoln

Dr. Minji Jeon is an Assistant Professor in the Department of Teaching, Learning and Teacher Education at the University of Nebraska-Lincoln.

Amanda Thomas, University of Nebraska, Lincoln

Purposefully Designing Integrated STEM Learning Experiences within Elementary Teacher Education (Work in Progress)

Introduction

Over a decade and since the publication of the Next Generation Science Standards (NGSS) document [1], the incorporation of engineering and engineering design in elementary grades has been fairly visible [2], [3]. Yet despite this adoption of engineering in elementary grades, many elementary teachers report a lack of time, teaching self-efficacy, and disciplinary knowledge for planning and enacting engineering learning experiences in their classrooms [4]. To address these challenges, professional development workshops and graduate courses have been developed to support elementary teachers' pedagogical content knowledge and teaching engineering self-efficacy. Indeed, recent studies have shown that these standalone professional development experiences can result in significant gains for in-service elementary teachers' teaching self-efficacy and reduce their perceived barriers to teaching engineering in their classrooms [5], [6]. However, this raises the question about how elementary preservice teachers (PSTs), those who are preparing to teach in elementary grades, are supported in planning and teaching engineering learning experiences prior to entering the teaching profession.

Engineering design in preservice elementary teacher education

The experiences offered in elementary teacher education programs can inform how elementary PSTs are equipped to implement engineering and engineering design-based lessons. For the most part, the emerging research on engineering education in preservice elementary teacher education is situated in elementary science teaching methods courses [7]-[9]. Perhaps due to the emphasis of engineering concepts and engineering design in the NGSS framework [1], the integration of engineering design activities may be more seamless and appropriate in these science methods courses. Other studies have examined teacher education programs with a different approach, whereby a separate course, usually focused solely on engineering design, is offered to elementary PSTs in addition to their core subject methods courses [10], [11]. These experiences during their undertaking of pedagogical coursework can provide elementary PSTs with the opportunity to engage in exemplary engineering design activities as learners, as well as reflect on them as future teachers.

Still, there are some studies that have focused on implementing engineering design experiences later in the teacher education program. These experiences occur during elementary PSTs' student teaching semester [12]-[14]. This body of work intentionally focuses on the student teaching semester as elementary PSTs can readily enact their engineering design-based lessons in an elementary classroom and reflect on these teaching experiences. Indeed, the enactment of engineering design learning opportunities in field-based experiences is also evident in some studies where engineering is emphasized in specific methods courses [7], [9]. These field-based experiences, whether they occur during student teaching or in conjunction with methods coursework, provide future elementary teachers with the opportunity to plan, teach, and reflect on their implementation of engineering design lessons.

With the exception of a few studies [15], [16], elementary PSTs overwhelmingly experience engineering design in a singular methods course. Moreover, they may do so devoid of a field-based experience, which may not be optimal, as these provide an opportunity for elementary PSTs to enact lessons purposefully designed for elementary classrooms. In this work in progress, we describe the integrated STEM approach we undertake as instructors of a STEM semester as part of a larger elementary teacher education program. Specifically, we analyze preliminary data collected in fall 2023 from elementary PSTs' integrated STEM lesson projects to investigate the following research questions: (1) How does a focus on sustainability provide elementary PSTs the opportunity to implement an engineering challenge or design in their integrated STEM lesson project? (2) What features are present in their engineering design activities?

About the STEM semester

The STEM semester that is the context for this work in progress is characterized by the five courses in which elementary PSTs are enrolled, including a mathematics content course, a mathematics methods course, a science methods course, an innovative learning technologies (ILT) course, and a course tied to a field-based experience in a rural educational setting. During the field-based experience, elementary PSTs are expected to be in their practicum classrooms two days of the week, over the span of 12 weeks of the STEM semester. While elementary PSTs in the STEM semester have already had a semester-long field-based experience (i.e., practicum) in the previous semester, the field-based experience in the STEM semester is the first that is directly tied with the methods courses they are enrolled in as students are expected to enact lessons they plan for these courses. Importantly, the STEM semester was designed to address the challenges of providing elementary PSTs with authentic integrated STEM learning and teaching experiences [17]. Therefore, the integrated approach of the STEM semester includes three cross-cutting themes: Coding & Robotics, STEAM & Creativity, and Engineering Design & Sustainability. Moreover, a core feature of the STEM semester is a collection of integrated STEM assignments that are shared among the three methods courses (mathematics, science, and ILT). The two shared assignments are an integrated STEM project and a STEM growth reflection.

As described earlier, learning experiences with engineering design tend to be concentrated within a single course of teacher education programs aimed at preparing future elementary teachers [7], [9], [11]. In contrast, the STEM semester features and elevates engineering design across each of the methods courses as part of our integrated STEM approach. Specifically, engineering design and sustainability is an overarching cross-cutting theme of the STEM semester. In Fall 2023, this theme spanned across four instructional weeks during the STEM semester. As engineering design is prominently featured in NGSS, the science methods course utilized the engineering design process [18] that involved elementary PSTs working collaboratively in problem-solving, formulating questions (NGSS Practice 1: Asking questions and defining problems), and designing, testing, and improving solutions (NGSS Practice 6: Designing solutions). For example, elementary PSTs constructed a device with dixie cups, paperclips, and straws to transport a ping-pong ball down the zipline (fishing line) and learned about the forces involved in a zipline. For the mathematics methods course, elementary PSTs utilized the engineering design process to plan cost-effective solutions to challenges tied to sustainability while engaging with elementary mathematics topics (e.g., money, addition, subtraction, multiplication). For example, given a budget, elementary PSTs designed spaghetti towers that could withstand hurricane wind speeds, which were simulated by a table fan. In the ILT course, elementary PSTs worked collaboratively to find the most efficient path using programming block-based languages and robotics. When they encountered issues, elementary PSTs engaged in debugging as part of testing and improving their path solutions with the help of the instructors and their peers.

Methods

This work in progress is from a larger study that utilizes a design-based research approach [19]. Design-based research is still a relevant approach in educational research (see [20]) as it allows for iterative cycles of (re)design, implementation, and analysis to better employ research-based pedagogy into practice, which in turn can inform research. For this larger study, the STEM methods instructional team has utilized design-based research to employ several iterations of the integrated STEM unit, each time refining the assignments to better engage elementary PSTs in creating and teaching authentic integrated STEM lessons to elementary students.

As mentioned earlier, the integrated STEM learning experience is one of the two assignments shared among three of the methods courses during the STEM semester. The assignment asked students to work as a grade-level team to create an integrated STEM learning experience that centers an authentic local science phenomena/topic that relates to the overarching theme of sustainability (e.g., crop residue burning and air quality) while also addressing science, mathematics, and technology content standards. Another unique aspect of the shared assignment is that elementary PSTs enact and teach their integrated STEM lesson to elementary students at their practicum placement.

During Fall 2023, 78 elementary PSTs (across three sections) were enrolled in the STEM semester. This STEM semester is the first professional phase of an elementary education program at a large, land-grant research university located in the midwestern region of the U.S. For this work in progress, we focused on the engineering design or challenge that was embedded in the integrated STEM learning experiences developed by elementary PSTs. As elementary PSTs worked in grade-level groups of 4 or 5, there were 18 grade-level projects in all, spanning grades K through 5.

Specifically, for this work in progress, we utilized a content analysis approach [21], [22] to examine how an engineering challenge or design was implemented in the integrated STEM lesson projects developed by elementary PSTs as well as explore what engineering education features are present in their engineering design activities. A content analysis approach was employed because this work in progress focuses on the written products from the integrated STEM projects, such as lesson plan slides [21]. In particular, to explore the engineering education features of the engineering design activities, the content analysis was guided by Moore and colleagues' [23] Framework for Quality K-12 Engineering Education (FQEE), which has been used to evaluate the quality of engineering education curricular materials, including lesson plans and experiences such as ours [14], [24].

Preliminary findings

RQ1: How does a focus on sustainability provide elementary PSTs the opportunity to implement an engineering challenge or design in their integrated STEM lesson project?

To answer the first research question, we analyzed the portion of the integrated STEM projects where elementary PSTs articulated engineering design connections. Overall, only 7 of the 18 (39%) groups incorporated a clear engineering challenge or design into their integrated STEM projects. Of those, five had aligned their engineering design challenges to a sustainability topic. In this preliminary work, we differentiate an integrated STEM activity from a design challenge on the topic of sustainability by the explicit inclusion of and attention to science, mathematics, and technology concepts. Put differently, an engineering design challenge would not necessarily need to attend to science, mathematics, and/or technology standards or concepts (e.g., design a solution or model to address water pollution). For example, one group developed an integrated STEM activity in which they asked students to "minimize the amount of pepper flakes (used to represent pollutant fertilizer) in a cup of water while maximizing the amount of water remaining." They incorporated science (learning about the composition of fertilizer), mathematics (representing remaining water as a fraction or percentage and in a graphical display), and technology (using a simulation to teach about fertilizer pollutants).

Other integrated STEM projects that included engineering design challenges focusing on sustainability were related to crop irrigation systems, wind energy, water pollution, and light pollution. These experiences targeted a broad range of elementary grades (second to fifth). From the lesson materials (e.g., presentation slides) submitted, we observed that groups that motivated their engineering design challenges with a clear linkage to sustainability provided elementary students with the opportunity to engage with STEM integration more authentically. Indeed, a focus on sustainability can provide a realistic context for elementary students to engage with engineering design and bridge connections to concepts learned across STEM disciplines [25].

Table 1. Engineering design connections of integrated STEM projects

Integrated STEM Project	**Engineering Design Connections**
Crop Irrigation Systems (Grade 2)	"We will incorporate engineering by having students create a simple model of an irrigation system."
Harness the Wind (Grade 4)	"Students will be constructing their own version of a Wind turbine with only 4 materials out of the total materials. "
Fighting Fertilized Water! (Grade 5)	"To incorporate engineering, students are given a design project where they try to minimize the amount of pepper flakes (used to represent pollutant fertilizer) in a cup of water while maximizing the amount of water remaining through the use of planning, collaboration, and two tools."

Build the Best Bridge (Grade 2)	"We are having students design and build a bridge and having them look at the problem of building a structure strong enough to hold many pennies."

RQ2: What features are present in their engineering design activities?

We utilized Moore et al.'s (2014) FQEE to address the second research question. In particular, we focused only on the Processes of Design (POD) and Issues, Solutions, and Impacts (ISI) indicators. This is because the integrated STEM lesson assignment included the following question prompts: (a) *Where are you going to encourage innovation and creativity?*; b) *How does this topic/project impact diverse populations of people locally, regionally, and/or globally?* Referring to Moore et al.'s FQEE [23], question (a) about innovation and creativity best aligns with the POD indicator whereas question (b) about the impact to diverse populations connects with ISI indicator. Future iterations of this assignment will include questions that ask elementary PSTs to plan for the inclusion of other engineering features into their projects.

For this portion, we selected four of the seven groups that incorporated engineering design to their integrated STEM lessons, as shown in Table 1, and analyzed their responses to the two questions prompts. Responses to question (a) about innovation and creativity included "[w]e have an activity where students engineer their own way to remove fertilizer from water to analyze how to clean pollution" (Crop Irrigation Systems), and "[w]e will encourage innovation and creativity through the building bridge activity. Students will have to be creative and budget friendly" (Build the Best Bridge). These responses demonstrate that elementary PSTs' perceptions of innovation and creativity were closely connected to providing students with the opportunity to engage in designing a model or solution to a problem, and then testing the design based on a set of criteria. These views on innovation and creativity are linked to engineering design, which in turn, indicate that these groups had an adequate knowledge of the engineering design process, as outlined by the POD indicator in the FQEE [23].

The results from the content analysis to question (b) about impact to diverse populations revealed that, for the most part, these selected groups had a deep understanding of the impact related to their integrated STEM project topic. One such response that highlights this deep understanding was "[t]his topic impacts diverse populations of people because people with less access to water need to develop efficient irrigation systems. If they don't, they won't be able to grow enough crops. Additionally, it's a global issue because everyone needs crops to survive, and almost all things come from at least one form of crop. Nearly 70% of freshwater in the world is used for irrigation and agriculture. This affects all populations" (Crop Irrigation Systems). Another indicated that their integrated STEM lesson project topic directly impacts students as the water pollution due to fertilizer "is a global issue, but this lesson provides a local example" (Fighting Fertilized Water!). In all, the PSTs in these groups developed integrated STEM lessons that not only addressed several STEM domains, including engineering design, but also attended to local sustainability issues that were relevant to their students' lives.

Conclusion and next steps

While the findings presented here are limited and preliminary, we found that the STEM semester provided elementary PSTs with the opportunity to develop rich integrated STEM learning experiences. We do note that more than half of these projects did not incorporate authentic engineering design challenges. However, the projects that did include and centered their lesson around an engineering design challenge had knowledge of the various steps of the engineering design process and a robust understanding of the impact of their topic locally as well as globally. A future iteration of the STEM semester with this shared assignment would include a microteaching session, where elementary PSTs could receive specific feedback from peers and instructors about the engineering design connections of their lesson. Additionally, we will also modify the assignment, so that all projects include an engineering design challenge and question prompts that ask elementary PSTs to plan for engineering features beyond innovation, creativity, and impact to diverse populations (e.g., design thinking, conceptions of engineers).

Our next steps include analyzing elementary PSTs' reflections about the enactment of their integrated STEM lesson as well as their views of how the STEM semester supported their knowledge of integrated STEM. For this work in progress, we only captured elementary PSTs' lesson plans for the integrated STEM learning experience. In contrast, the reflections include their post-lesson perceptions of how the lesson went. These reflections were submitted as final projects, and at the time of writing, have not yet been analyzed. We anticipate these reflections will also help inform the design of future iterations of the shared STEM assignments to better support elementary PSTs.

References

[1] NGSS Lead States, *Next generation science standards: For states, by states*. Washington, DC: National Academies Press, 2013.

[2] B. M. Capobianco, J. Radloff, and J. D. Lehman, "Elementary science teachers' sense-making with learning to implement engineering design and its impact on students' science achievement," *Journal of Science Teacher Education*, vol. 32, no. 1, pp. 39-61, 2021.

[3] S. Y. Yoon, H. Diefes-Dux, and J. Strobel, "First-year effects of an engineering professional development program on elementary teachers," *American Journal of Engineering Education (AJEE)*, vol. 4, no. 1, pp. 67-84, 2013.

[4] R. Hammack and T. Ivey, "Elementary teachers' perceptions of K-5 engineering education and perceived barriers to implementation," *Journal of Engineering Education*, vol. 108, no. 4, pp. 503-522, 2019.

[5] R. Hammack, P. Gannon, C. Foreman, and E. Meyer, "Impacts of professional development focused on teaching engineering applications of mathematics and science," *School Science and Mathematics*, vol. 120, no. 7, pp. 413-424, 2020.

[6] J. Watkins, M. Portsmore, and R. D. Swanson, “Shifts in elementary teachers' pedagogical reasoning: Studying teacher learning in an online graduate program in engineering education,” *Journal of Engineering Education*, vol. 110, no. 1, pp. 252-271, 2021.

[7] B. M. Capobianco, J. Radloff, and J. Clingerman, “Facilitating preservice elementary science teachers’ shift from learner to teacher of engineering design-based science teaching,” *International Journal of Science and Mathematics Education*, vol. 20, no. 4, pp. 747-767, 2022.

[8] R. Hammack and I. H. Yeter, “Exploring pre-service elementary teachers’ engineering teaching efficacy beliefs: A confirmatory analysis study (fundamental),” in *2022 ASEE Annual Conference & Exposition*, 2022.

[9] M. Perkins Coppola, “Preparing preservice elementary teachers to teach engineering: Impact on self-efficacy and outcome expectancy,” *School Science and Mathematics*, vol. 119, no. 3, pp. 161-170, 2019.

[10] D. R. Raman, M. H. Lamm, S. Sundararajan, K. M. Tank, and A. T. Estapa, “Board# 109: Baby Steps toward Meeting Engineering-rich Science Standards: Approaches and Results from a Short ‘What is Engineering?’ Course for K-5 Pre-service Teachers (Work in Progress),” in *2017 ASEE Annual Conference & Exposition*, 2017.

[11] D. L. Webb and K. P. LoFaro, “Sources of engineering teaching self-efficacy in a STEAM methods course for elementary preservice teachers,” *School Science and Mathematics*, vol. 120, no. 4, pp. 209-219, 2020.

[12] J. Pleasants, J. K. Olson, and I. De La Cruz, “Accuracy of elementary teachers’ representations of the projects and processes of engineering: results of a professional development program,” *Journal of Science Teacher Education*, vol. 31 no. 4, pp. 362-383, 2020.

[13] J. Pleasants, K. M. Tank, and J. K. Olson, “Conceptual connections between science and engineering in elementary teachers’ unit plans,” *International Journal of STEM Education*, vol. 8, pp. 1-17, 2021.

[14] K. M. Tank, M. DuPont, and A. T. Estapa, “Analysis of elements that support implementation of high-quality engineering design within the elementary classroom,” *School science and mathematics*, vol. 120, no. 7, pp. 379-390, 2020.

[15] A. E. Adams, B. G. Miller, M. Saul, and J. Pegg, “Supporting elementary pre-service teachers to teach STEM through place-based teaching and learning experiences,” *The Electronic Journal for Research in Science & Mathematics Education*, vol. 18, no. 5, pp. 1-22, 2014.

[16] D. DiFrancesca, C. Lee, and E. McIntyre, “Where Is the" E" in STEM for Young Children? Engineering Design Education in an Elementary Teacher Preparation Program,” *Issues in Teacher Education*, vol. 23, no. 1, pp. 49-64, 2014.

[17] D. Menon, A. S. Bauer, K. L. Johnson, E. F. Hasseler, A. Thomas, R. Martinez, and G. Trainin, "Greater than the Sum of its Parts: Centering Science Within Elementary STEM Education," in *Reforming Science Teacher Education Programs in the STEM Era: International and Comparative Perspectives,* S. M. Al-Balushi, L. Martin-Hansen, and Y. Song (Eds.), Cham, Switzerland: Springer International Publishing, 2023, pp. 233-250.

[18] P. S. Lottero-Perdue, "Engineering design into science classrooms," in *Teaching science to every child: Using culture as a starting point,* J. Settlage, S. A. Southerland, L. K. Smetana, and P. S. Lottero-Perdue (Eds.), Routledge, 2017, pp. 207–266.

[19] T. Anderson, and J. Shattuck, "Design-based research: A decade of progress in education research?" *Educational researcher*, vol. 41, no. 1, pp. 16-25, 2012.

[20] C. E. Mundy, M. Potgieter, and M. K. Seery, "A design-based research approach to improving pedagogy in the teaching laboratory," *Chemistry Education Research and Practice*, vol. 25, no. 1, pp. 266-275, 2024.

[21] M. Schreier, "Qualitative Content Analysis" in *The SAGE Handbook of Qualitative Data Analysis*, pp. 170-183, 2014.

[22] S. Stemler, "An overview of content analysis," *Practical assessment, research, and evaluation*, vol. 7, no. 1, pp. 1-6, 2001.

[23] T. J. Moore, A. W. Glancy, K. M. Tank, J. A. Kersten, K. A. Smith, and M. S. Stohlmann, "A framework for quality K-12 engineering education: Research and development," *Journal of pre-college engineering education research (J-PEER)*, vol. 4, no. 1, 2014.

[24] C. Maiorca and M. J. Mohr-Schroeder, "Elementary preservice teachers' integration of engineering into STEM lesson plans," *School Science and Mathematics*, vol. 120, no. 7, pp. 402-412, 2020.

[25] C. I. Sneider and M. K. Ravel, "Insights from two decades of P-12 engineering education research," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 11, no. 2, pp. 1-36, 2021.