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Board 171: The Design of a Course to Train STEM Pre-Service Teachers (Work-in-progress)

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Dr. Maram Alaqra has over 17 years' experience in education, working across higher education and K-12 settings. Dr. Alaqra has taught graduate and undergraduate courses at Texas A&M University, which included over eight years of research experience on STEM education. Having spoken widely on STEM education internationally and throughout the US, Dr. Alaqra has also been part of large-scale STEM education research projects funded by the National Science Foundation, National Institute of Health, and Department of Education.

Dr. Alaqra's research agenda has emphasized culturally relevant teaching and learning through designing culturally sensitive learning environments for students to improve STEM self-efficacies and interests. Research interests include: STEM education, culturally relevant instruction, STEM self-efficacy, community-based learning, and 21st Century skills.

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She has extensive experience in providing engineering outreach programming for PK-12 educators and students, including coordinating an annual virtual STEM conference with global reach for educators, creating and implementing professional development on embedding engineering practices into K-12 science, providing support for student researchers in grades 6-12 to participate in the state science & engineering fair, and fostering K-12 students' interest in engineering careers through campus engagement events. In addition, she has multiple years of experience in secondary science curriculum development; science classroom instruction in middle school, high school, and college; and STEM presentations/workshops for educators in national, state, and local settings.

She is pursuing a Doctor of Philosophy in Curriculum and Instruction with the Texas A&M University School of Education and Human Development in Science Education, STEM/Engineering. Research interests include: professional development on engineering practices/design for in-service K-12 science educators, project-based and inquiry-oriented teaching strategies at pre-college levels for preservice STEM teachers.

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Director of Spark! PK-12 Engineering Education Outreach with Texas A&M Engineering. Her team strives to ignite and foster an engineering spirit from pre-kindergarten through the 12th grade. Dedicated to harnessing the educational power of the maker movement, Spark! was awarded a mobile makerspace from Andeavor, and strives to empower the PK-12 educator by offering professional development through its Maker U program. Spark! is also the new home of the State Science and Engineering Fair of Texas hosting 4,000 6th-12th grade students.

Prior to Texas A&M, she was a Master Teacher in Spring Branch Independent School District for 26 years and a Department Chair for Memorial High School in Houston, Texas. Always interested in unleashing the imagination of students, she incorporated 3D printing in her classroom for 18 years, and was awarded the PTA District School Bell Award for her service in STEM Education.

She has been a leader in engineering education in the state of Texas throughout her career. Projects include creating and leading new teacher boot camps, developing the Texas standards for the Math/Physical Science/Engineering teacher certification and most recently developing the Texas Essential Knowledge and Skills frameworks in STEM education. Widely known for her work with Project Lead The Way (PLTW), she served as the State Lead Master Teacher training over 700 teachers in PLTW Core Training Institutes for 13 years.

Shelly holds a B.S. degree in Industrial Design and Development and a M.Ed. in Teacher Leadership. She believes in empowering teachers, who then empower students to go out and change our world.

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The Design of a Course to Train STEM Pre-Service Teachers (Work in Progress)

Abstract

In pre-college levels, integrated science, technology, engineering, and mathematics (STEM) are often taught by science or mathematics teachers. These teachers lack the engineering and technology background and they do not necessarily use project-based and inquiry-oriented instructional strategies. To close the gap in the qualified STEM education teacher workforce, the authors developed and piloted a novel course to train preservice STEM teachers to effectively employ project-based and inquiry-oriented teaching strategies at pre-college levels. This 3-credit research and design experience course was piloted in the Spring 2023 semester. The preservice STEM teachers, enrolled in the course, engaged in hands-on activities, engineering project-based training, inquiry-based learning techniques through research training, makerspace training, field experience, and mentorship. The course comprised two parts. In part I, the students received research training. In part II, the students engaged in engineering design and makerspace professional development. In this paper, we report on the course design elements and the impact of the course activities on students' self-efficacy in teaching STEM subjects using emerging technology, as well as their teaching approaches and understanding of student learning. The authors conducted a mixed methods study and collected both qualitative and quantitative data. Preliminary results of the multiyear study are presented. Initial findings indicate a heightened confidence of the students in their ability to deliver STEM content in secondary classrooms. Students improved their teaching approaches and reported positive experiences with the course.

Key words: K-12 Engineering Education, pre-service teachers, Project-based learning, Engineering design

Introduction

Engineering and technology play pivotal roles in shaping most aspects of modern life, including but not limited to, communication, medicine, economy, infrastructure, transportation, and education. Researchers and educators are aware of the importance of technology and engineering in the everyday lives of citizens. Multiple efforts have been made to integrate engineering and technology into K-12 school curricula [1], [2]. These efforts require professionals who are trained in engineering and technology subjects and who are capable of designing and offering integrated STEM instruction at K-12 levels. Among the efforts undertaken to train in-service teachers to teach engineering and technology are professional development (PD) sessions and collaborations between universities and school districts [3-7]. The PD sessions and other training for in-service teachers often yield positive results. Typically, teachers who have intrinsic interest and are willing to integrate engineering and technology choose to attend PD sessions and other training, while those who are not interested or not willing to integrate these subjects do not participate. The efforts to expand the integration of engineering and technology into school subjects will remain incomplete without professionally trained teachers in engineering and technology education.

To respond to the needs of qualified teachers in engineering and technology education, a group of faculty and researchers at Texas A&M University in the United States collaborated to design and offer a special course. Engineering undergraduate students who are interested in teaching engineering and technology in K-12 levels were the targeted student population. The course, titled "Engineering Design & Project-Based Learning," was intended to train engineers in a way that the engineers will be able to translate complex theory into age-appropriate hands-on learning activities in the classroom, for example, robot building. The course was designed to show students that the disciplinary knowledge of engineering, technology, science, and mathematics was not isolated from one another.

In this work-in-progress paper, we describe the course design and delineate the types of activities students completed. In addition, we share preliminary findings of a multi-year mixed methods study designed to capture students' learning experiences and changes in their teaching approaches and self-efficacies to teach engineering and technology subjects in K-12 classrooms.

The Design Characteristics of the "Engineering Design & Project-Based Learning" Course

The semester-long course was divided into two main parts. In Part I, we provided research training to the students. In Part II, students engaged in engineering design and maker space professional development activities.

In part I, our senior engineer faculty member taught lectures with PowerPoint presentations and offered workshops and lab sessions where students engaged in discussions, open-ended activities, and design challenges. The course instructors took the lead in organizing and delivering the content of these meetings in Part I. Our senior education faculty member taught a lecture about the state's essential knowledge and skills expectations. How to locate and utilize those state standards were explained to the students. Additionally, students were informed about the Next Generation Science Standards [1] along with how to locate and make use of them. In Table 1, the course content covered in Part I is listed.

Table 1. *The list of the course content included in Part I.*

• Research Orientation: - What is research - Types of research - How to plan your research - Identifying your topic - Conducting literature review - Writing hypotheses or research questions - Using EndNote bibliography software to cite and document related work - Age-appropriate research- discussing linking

• Applied Research: - Project-based design - Defining the problem - Managing the engineering project design process - Create Gantt Chart, Network Logic Diagram, and Work Breakdown Structures - Surveying technology to use in your engineering design
• Next Generation Science Standards (NGSS): - Explaining NGSS and its translation into the secondary classroom

In part II of the course, students took leadership roles. Students visited local schools, competitions, and other educational settings where they observed secondary school students. They interacted with the students whom they met in those locations. We invited middle school students to join our class meetings on the university campus and our pre-service STEM education teacher participants taught lessons to the students in their classroom. Our pre-service STEM teachers attended the Texas Science & Engineering Fair held on the university campus where they served as judges to evaluate students' STEM projects. The activities students completed in the course are summarized in Table 2.

Table 2. *Activities students completed*

(1) Research training on how to design and conduct inquiry-based learning activities
(2) Professional development training in engineering design and makerspace
(3) Intensive engagement in engineering design projects
(4) Mentoring support
(5) Early field teaching experiences

Our goal has been to train pre-service teachers who could effectively implement inquiry-oriented and project-based learning in the secondary classroom. We utilized a set of evidence-based interventions to promote innovation and novel engineering hands-on activities in the classroom [8-10]. The project team trained the participating students in the course through several research activities, mentoring, makerspace training, and field experiences. We asked the preservice teachers to effectively utilize inquiry-oriented and project-based learning [7], [8]. It is critical for preservice teachers to be confident in their abilities to integrate new technology into pedagogical practices and teach engineering innovatively and effectively. We anticipated that preservice teachers' beliefs in their abilities to teach integrated STEM education would have improved because of their participation in the course activities. To evaluate the effect of the course activities on students' learning outcomes, we investigated the students' self-efficacy and approaches to teaching.

Integrated STEM Teaching Self-Efficacy

We employed Bandura's theory of self-efficacy in our theoretical framework [11]. The course activities students participated in, including research training, mentoring, maker space training, and field experiences had the potential to enhance students' self-efficacy. Self-efficacy is often defined as one's belief that one can be successful in their effort in a particular field. When the field is 'integrating new technology into one's pedagogical practice,' we defined this as prospective STEM teachers' belief that they can successfully teach integrated STEM innovatively and effectively. Bandura explained that four principal sources impact the development of one's self-efficacy over time [14]. These sources are: (i) past performance, (ii) vicarious experiences, (iii) verbal persuasion, and (iv) physiological responses. Based on the sources of the self-efficacy framework, prospective STEM teachers' integrated STEM education self-efficacy is mainly influenced by the success of their completed teaching activities (past performance). Another source is observing others and imagining through their feelings and their actions of successful pedagogical practices (vicarious experiences). If a student is told that they can successfully teach integrated STEM, it is more likely that they will have higher integrated STEM teaching self-efficacy (verbal persuasion). If the student reacts negatively to the integrated STEM education teaching tasks and develops several negative emotional clues including, a racing heart, blushing, sweating, headaches, etc. as they perform the teaching act, it is more likely that the students will have a negative teaching self-efficacy (physiological responses).
In the course, we adopted the Science Framework for K-12 Science Education that provided the blueprint for developing the Next Generation Science Standards (NGSS) [1]. The Framework listed several disciplinary core ideas that all K-12 students should learn with increasing depth and sophistication. The eight practices of science and engineering education that the Framework identified as essential for all students to learn and describe are listed in Table 3.

Table 3. *Essential practices of science and engineering education*

(1) Asking questions (for science) and defining problems (for engineering)
(2) Developing and using models
(3) Planning and carrying out investigations
(4) Analyzing and interpreting data
(5) Using mathematics and computational thinking
(6) Constructing explanations (for science) and designing solutions (for engineering)
(7) Engaging in argument from evidence
(8) Obtaining, evaluating, and communicating information

In teaching the course, the university faculty created an applied research training and mentorship program for student participants. Faculty also created a professional development training program in engineering design and makerspace. A STEM outreach program that has been on campus already joined the efforts to teach the preservice STEM teachers. The outreach program on campus generated and delivered "programs for elementary, middle, and high school students, as well as outreach to science, math, and career and technical education (CTE) educators throughout the state, to help attract young minds to engineering."

Methods

Research Design

We conducted a mixed methods design [12-14] to explore the students' experiences in the course and the effectiveness of the course activities on their teaching approaches and self-efficacy to teach integrated STEM lessons using the newly emerged technologies. In the Spring 2023 semester, four students enrolled in the course. Because this is a relatively low number of participants for a mixed methods study, we will be collecting more data in the upcoming semesters merging the new data with the existing data, and running the analyses again. The research design described in this paper will be iterated when we offer the same course in the upcoming semester and collect additional data from future study participants. In the present study, we anticipated that the four students who completed the course activities would have positively improved their self-efficacies to teach integrated STEM lessons using newly emerged technology and incorporating inquiry-based learning into the K-12 classroom. We received approval from the university's Institutional Review Board to conduct the evaluations as a research study.

Research Questions

We asked two research questions: "*What were the changes in preservice teachers' approaches to teaching after completing the course activities*?" and *"What were the preservice teachers' lived experiences and self-efficacy in teaching integrated STEM lessons using the newly emerged technologies after completing the course activities?"*

Research Instruments, Data Collection, and Analyses

A questionnaire was designed to capture the students' demographics. To capture the students' lived experiences in the course and their self-efficacies to teach integrated STEM lessons using the newly emerged technologies, we designed a semi-structured interview protocol with open-ended questions [12], [13]. Interview data were analyzed using the qualitative data analyses methods [13-15]. We utilized the Approaches to Teaching Inventory (ATI) to capture the students' approaches to teaching and understanding of student learning before and after the course. We administered the survey once at the beginning of the semester and then once again after the semester was completed. Three students completed the pre-survey, and four students completed the post-survey. The differences between the students' pre- and post-responses explained the extent to which our student participants changed their approaches to teaching and understanding of student learning. The data collected from the ATI survey were quantitative [13]. Because of the small number of participants, we only report the differences between the post and pre-responses (gains scores in other words). The research design described here will be iterated when the number of participants increases. The ATI was a five-point Likert scale with 16 items. Eight items in the ATI instrument captured the respondents' "Information Transmission- Teacher Focused" (ITTF dimension) teaching orientation. Other eight items in the instrument captured the respondents' "Conceptual Change- Student Focused" (CCSF) teaching orientation. A high average score in the ITTF items indicated that the respondent's teaching orientation was "Information Transmission- Teacher Focused" whereas a high average score in the CCSF items indicated that the respondent's teaching orientation was "Conceptual Change- Student Focused." We interviewed all four student participants after the semester was completed. One of the researchers talked to the students individually. The semi-structured interview protocol guided the conversations. The conversations were audio-taped and then transcribed. The transcriptions were analyzed using the constant comparative method and we employed open, axial, and selective coding strategies [15]. The main themes were generated and reported with sample quotes [14]. How People Learn (HPL) framework [8] and evidence-based pedagogies [16-23] promoted learner-centered and student-focused teaching approaches to increase students' persistence in STEM fields. A more student-focused instruction required less emphasis on teacher-focused approaches that often resulted in the sole purpose of transmitting information to the students. Ideally, the CCSF scores should increase and the ITTF scores should decrease if the respondents were more inclined to teach student-centered and conceptual change-oriented teaching strategies.

Findings

In our pilot offering of the course, our four student participants' CCSF response means increased to 3.41 from 2.96. Similarly, their ITTF score means also increased to 3.28 from 2.96. The analyses of the transcribed conversations generated seven themes. Next, we present these themes.

Theme 1- Engineering Design: Students' understanding of engineering design and processes improved because of the course. The course introduced engineering design to the students even though they had taken several engineering courses. Students discussed how other engineering courses focused on one field in a micro and very atomistic view while this course provided them with a well-structured and prepared general engineering design. A student reported: *"We learned a lot about the engineering design process, which is a truly valuable skill set to have that I really didn't have before entering this course."*

Theme 2- Gaining New Knowledge and Empowerment: Students reported that their experience in the project was a valuable experience where they learned new things and gained new knowledge. The experience they had in the course was eye-opening for them and it helped them grow as learners and as future educators. Students reported: *"This class requires diverse thinking and provides opportunities for leadership position"* and *"This course provided us with a different structure allowing for different learning gains."*

Theme 3- Learning New Things about Teaching and Practicing Teaching: Students reported that they were exposed to a teaching and learning experience. They discussed how they learned throughout the course new things about teaching and the principles of teaching and learning. Participants noted the practical portion of the course where they had to teach students and indicated how beneficial the teaching practice was for them to know what teaching takes and all the preparations that happen behind the scenes. Students noted: "*Being a teacher and teaching other people how to go through that process was so valuable. I'm so grateful that I had that experience," "In regard to teaching, I learned a lot about the preparation that goes on behind the scenes,"* and *"I learned that you have to have a lot of patience with yourself, obviously you have to have patience with your students, but you also have to have patience with yourself."*

Theme 4- A Unique Learning Experience: Students reported that, unlike other courses they had taken, in this course, they had the opportunity to do a lot of hands-on activities. The course enhanced students' learning and allowed them to explore new things so they could convey it when they did the teaching tasks. Sample quotes were: *"We got a lot of instruction, but then we also got to have practice delivering that instruction," "The course was very different; we had a lot of feedback and interaction,"* and *"My more creative side was engaged."*

Theme 5- Gaining New Skills: Students learned new skills and gained new knowledge in the course, and they improved their views toward teaching. They reported that the program was *"eye-opening"* for them and changed the way they perceive learning and teaching. The program made them more accepting of students' mistakes and their student-centered learning approach.

Theme 6- Adopting Students' Perspective: Students reported that by being the teacher as a course assignment in this course, they experienced being the educators. That learning experience allowed them to "put on their teacher's hat" and get how it feels to own their learning to convey it to students. The students discussed how they learned to be "patient" with themselves and how to tailor their teaching towards students' level of knowledge. This experience changed the way students viewed the learning process and made them think differently about teaching.

Theme 7- Improvement and Changes in Students' Attitudes Towards Teaching: Students reported that participation in this course changed their attitudes and views toward teaching. Students reported that they gained more confidence in their ability to teach in general. Sample quotes were: *"I have more confidence to teach because we had hands-on opportunities to practice teaching. When the students would come here, and we taught them multiple times."*

Conclusion

The number of our participants was very small. For that reason, we do not generalize the results. However, the qualitative findings indicated that the confidence of our preservice teachers in their ability to deliver STEM content in secondary classrooms and their teaching approaches were improved after the semester was completed. Our student participants reported positive experiences with the course activities. Among the most significant findings we found was that this course allowed the participants to practice teaching engineering and technology topics to students. In the upcoming semesters, we will offer the same course and iterate the design of the research described in this paper. We will merge the new data with the existing data and run the analyses. If we see major differences in the findings, we will report them in another publication. STEM teacher education programs similar to our program can use the course design and its evaluation as a model to offer a similar course and evaluate its impact. With the increased opportunities to learn how to teach integrated engineering and technology in K-12 levels, we will have a stronger STEM education teacher workforce and this may positively affect the number of students who are interested in STEM fields and who are well qualified to continue their education in STEM degree. To help improve the STEM pipeline, we recommend other teacher education programs to design and offer courses similar to the one discussed in this paper.

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