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BOARD # 205: Exploring Pre-service Teachers' Perceptions of Integrating Engineering Design and Culturally Responsive Pedagogy in STEM Education (Work in Progress)

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“Exploring Pre-service Teachers’ Perceptions of Integrating Engineering Design and Culturally Responsive Pedagogy in STEM Education” (Work in Progress, Diversity)

As the integration of the engineering design process into K-12 science curricula becomes a reality, particularly in Texas, the preparation of pre-service science teachers to effectively implement this approach is more critical than ever. This study explores how pre-service secondary science teachers understand and integrate the engineering design process (EDP) and culturally responsive pedagogy (CRP) into their instructional practices. Specifically, it investigates how their exposure to these teaching methods during their preparation shapes their instructional beliefs, lesson planning, and approaches to student-centered learning in diverse classrooms.

The pre-service teachers in this study participated in a six-week summer program designed to address barriers to STEM education for economically and socially disadvantaged students. The program provided structured training on CRP, including developing students’ funds of knowledge and culturally responsive mentoring, supporting teachers in incorporating these practices into lesson planning and instruction. Pre-service teachers engaged in workshops, reflective journaling, interactive activities, and actual teaching experiences with students. Throughout the program, mentors were supported with training in culturally responsive mentoring practices to ensure ongoing guidance.

To assess the impact of this experience, data were collected through semi-structured interviews conducted after the program and a post-program survey. Findings suggest that exposure to EDP and CRP with guided implementation experiences solidified participants’ beliefs, encouraged them to apply these methods in real classroom settings, and clarified their approaches to culturally responsive and student-centered STEM teaching. This work contributes to our understanding of enhancing pre-service and in-service teacher education, supporting the development of diverse and inclusive STEM learning environments.

1. Introduction

Teacher beliefs play a critical role in shaping instructional practices, as established by Dewey (1933) [1] and Rokeach (1968) [2]. Building on Bandura's social cognitive theory (1986, 1997) [3], which highlights the influence of outcome expectancies on actions, this study examines how pre-service teachers' beliefs evolve and inform their engagement with the engineering design process (EDP) and culturally responsive pedagogy (CRP). The integration of EDP into K-12 science education enhances student learning by connecting scientific concepts to real-world applications. For example, designing water filtration systems allows students to apply scientific principles to tangible, problem-solving contexts. The National Academy of Engineering and the National Research Council [4] emphasize EDP's potential to improve problem-solving skills, deepen STEM understanding, and promote technological literacy through hands-on learning.

In parallel, CRP provides a framework for engaging diverse learners by incorporating their cultural identities, experiences, and perspectives into instruction. It validates students' backgrounds, fosters a sense of belonging, and promotes academic achievement through meaningful and relevant teaching. Despite its benefits, teacher preparation programs often fail to equip educators with the skills to implement EDP and CRP effectively. STEM teacher preparation programs devote limited attention to engineering education and culturally responsive practices, leaving many pre-service teachers underprepared to integrate these approaches [5], [6]. As states like Texas mandate the inclusion of engineering practices in K-12 science curricula, addressing this gap becomes increasingly urgent.

This study investigates how pre-service secondary science teachers perceive and integrate EDP and CRP into their instructional practices. Specifically, it examines how participation in a summer research and professional development program, funded by the National Science Foundation and hosted at the University of Houston, influences their instructional beliefs, lesson planning, and approaches to student-centered learning in diverse classrooms. By focusing on the intersection of EDP and CRP, this work contributes to research aimed at strengthening STEM teacher preparation and fostering inclusive instructional environments.

1.1 Program Structure

The six-week summer program was designed as a collaborative initiative between the University of Houston's College of Natural Sciences and Mathematics STEM teacher preparation program, teachHOUSTON, the Tilman J. Fertitta Family College of Medicine., and local community leaders. This initiative aimed to provide high school students, undergraduate STEM majors, and medical students with enriching STEM learning experiences. Participants engaged in STEM research, hands-on instruction, and professional development focused on best practices in research, teaching, and mentoring. The program followed a structured progression, gradually introducing and reinforcing engineering design and culturally responsive teaching practices. Participants engaged in a combination of instructional training, research, and hands-on teaching experiences, ensuring they had both conceptual knowledge and practical application opportunities. Throughout the program, culturally responsive mentoring played a key role, with mentors receiving ongoing support to ensure they could guide participants in applying CRP principles in their lesson planning and teaching. Rather than solely discussing EDP and CRP in theory, participants applied these frameworks by designing and delivering STEM lessons that may have aligned with engineering design principles while incorporating culturally responsive teaching strategies. Pre-service teachers adapted their lessons based on student engagement and feedback, adjusting instructional methods to better connect with diverse learners. After each teaching session, they engaged in structured self-reflection, assessing their strengths and identifying areas for improvement to refine their instructional practices further. In addition to their instructional responsibilities, pre-service teachers participated in a summer course titled Research Methods in STEM, offered through the teachHOUSTON program at the University of Houston, where they developed their own instructional materials under the mentorship of program directors. These lessons were then taught to high school participants, allowing pre-service teachers to apply their learning in a real-world classroom environment. These lessons were designed to integrate engineering design principles and culturally responsive pedagogy, ensuring meaningful connections between STEM content and students' lived experiences. The curricula developed by pre-service teachers under the mentorship of program directors included structured lesson plans and instructional materials designed to integrate engineering design principles and culturally responsive pedagogy. Lessons on Reverse Engineering Hair Dryers, Protein Synthesis, Growth Mindset in STEM, and College Readiness & STEM Career Exploration provided essential frameworks that participants created to align with their students' cultural backgrounds and experiences. By developing these materials, pre-service teachers designed their own lessons, using real-world connections and student narratives to make STEM learning more meaningful.

Over the years, the program has expanded increasing the number of university research labs involved and deepening partnerships with local community organizations and schools. The program's emphasis on culturally responsive teaching has played a key role in its success, helping students connect STEM learning to their lived experiences while preparing future STEM educators and professionals to foster inclusive and engaging learning environments.

1.2 **Theoretical Framework: Teacher Pedagogical Beliefs**

This study is grounded in the theory of teacher pedagogical beliefs, which explores how teachers' perceptions shape their instructional practices. Dewey (1933) posited that beliefs are formed through experiences and interactions, often unconsciously [1]. Later, Rokeach (1968) further defined beliefs as underlying assumptions that drive decision-making [2], while Bandura's social cognitive theory (1986) emphasized that beliefs influence behavior through outcome expectancies, shaping instructional choices [7]. Decades of research have established a strong connection between teacher beliefs and pedagogical practices. Studies indicate that teachers' beliefs directly influence classroom behavior, instructional planning, and implementation of teaching approaches including culturally responsive pedagogy [6]. Given the central role of beliefs in shaping teaching strategies, documenting pre-service teachers' pedagogical beliefs is essential to understanding how they integrate EDP and CRP into instruction.

2. Relevant Literature

EDP is "an approach encompassing identification of a problem and developing a model that is refined through data analysis to produce a solution consisting of social and technological elements" [6]. It is a structured process that engineers use to solve problems within constraints, addressing prior design limitations and generating ideas for product or system improvements. Training future teachers in EDP not only prepares them to integrate engineering concepts into STEM instruction but also increases secondary learners' exposure to engineering practices, which can encourage them to pursue STEM coursework and careers. Research indicates that EDP helps frame scientific problems in culturally relevant ways, making STEM more accessible to diverse learners [6]. Despite its benefits, pre-service teachers often struggle to apply EDP effectively, particularly in integrating fundamental mathematics and physical science concepts into decision-making using scientific language [8]. However, incorporating engineering design coursework into teacher preparation has been shown to increase self-efficacy in teaching STEM with EDP, yielding consistent results across gender identities and academic disciplines [9]. This suggests that EDP has the potential to support inclusive instruction.

Culturally responsive pedagogy (CRP) aligns with inclusive instruction by emphasizing academic success, culturally competent discourse, and sociopolitical awareness [10]. Both CRP and EDP promote meaningful connections between students' cultural identities and their learning experiences. While CRP is widely recognized for addressing disparities in STEM education, its application within K-12 engineering contexts remains limited. Many educators lack awareness of its benefits, which hinders its implementation in engineering instruction [11]. Revelo et al. [11] highlight the importance of pre-service teacher training in equipping educators with the skills to integrate CRP and EDP effectively. Manuel et al. [6] introduced the concept of culturally responsive engineering design pedagogy (CREDP), a framework that supports the simultaneous enactment of both CRP and EDP. By adopting this dual framework, educators can create STEM learning environments that are both culturally relevant and engineering-focused, bridging the gap between theory and practice.

3. Methods

This study uses a qualitative research design grounded in constructivist and culturally responsive frameworks to explore integrating the engineering design process (EDP) and culturally responsive pedagogy (CRP) in teacher preparation. By leveraging individual interviews and post-surveys, this research aims to identify emergent themes that shape preservice teachers' beliefs, challenges, and strategies for implementing EDP and CRP. This approach aligns with the call for integrating inclusive pedagogical strategies in STEM education to address disparities for historically underrepresented populations [10] [11] [12].

3.1 Participants

We sent our Institutional Review Board (IRB) approved recruitment email to potential study participants. Study participants were recruited from among pre-service teachers who had participated in the summer professional development implemented since 2022. Our recruiting efforts yielded three participants, all of whom were biology majors and minoring in STEM education through teachHOUSTON. Each participant aspired to teach secondary STEM upon graduating. Sarah, a participant from Cohort 1 (2022), identified as Two or More Races (Black and South Asian), Non-Hispanic, and Female. Ellie, a participant in both Cohort 2 (2023) and Cohort 3 (2024), identified as White, Hispanic, and Female. Owen, from Cohort 3 (2024), identified as White, Non-Hispanic, and Male. The diversity in their racial, ethnic, and gender backgrounds provided a valuable lens for exploring how their lived experiences influenced their engagement with EDP and CRP during the program.

3.3. Data Collection

Data for this study were collected through semi-structured individual interviews and reflective journal prompts, providing rich qualitative insights into how pre-service teachers conceptualized and applied the engineering design process (EDP) and culturally responsive pedagogy (CRP). These methods allowed for an in-depth exploration of participants' evolving beliefs, instructional strategies, and operationalized definitions of EDP and CRP in STEM teaching. Participants were interviewed between one and three years after completing the program, allowing for reflections on both their immediate experiences and how their learning influenced their teaching over time. Semi-structured interviews were conducted via Zoom, with two research team members facilitating the discussions individually or collaboratively. To establish rapport, interviewers began each session by sharing their fields of study and affiliations, reinforcing that participants' lived experiences were valued contributions to both the research team and the academic community [13]. The interview protocol was informed by participants' reflections from their journal prompts, ensuring that responses built on their documented perspectives. During the interviews, participants were asked to reflect on their instructional approaches and anticipated classroom applications of EDP and CRP. Questions included: How do you see yourself incorporating EDP in your future lessons? How have you? What benefits do you think EDP brings to STEM teaching, and what challenges might you face in using it? Did the program give you specific strategies to use CRP in your teaching? If so, can you share an example?

3.4 Data Analysis

The analysis was informed by a theoretical understanding of teacher beliefs as pivotal in guiding instructional practices. This perspective provided a lens to interpret participants' reflections on their teaching experiences and their engagement with EDP and CRP. Thematic analysis guided the data analysis process, following Braun and Clarke's six-phase framework [14]. This included: (1) Data familiarization, (2) Generating initial codes, (3) Searching for themes, (4) Reviewing themes, (5) Defining and naming themes, and (6) Producing the final report. Initially, we familiarized ourselves with the data by reading and rereading the transcripts and open-ended survey responses, highlighting quotes of interest. Inductive coding was then applied to identify patterns in the data without tying them to any specific theoretical framework. Initial codes, such as views that EDP/CRP provides opportunities for exploring, critical thinking, and engaging interest, were organized into the broader category of beliefs. We define beliefs as ideas or opinions people hold to be true. When participants described their practical experiences in the six-week program and in post-program contexts, we grouped these statements into the "practice" category. Practices are actions or behaviors that individuals engaged in (i.e., what people did). Codes that described how EDP/CRP informed decisions in classroom settings were organized under the "approaches" category. These statements were usually supported by theoretical frameworks and abstractions.

Peer debriefing sessions ensured that themes were consistently applied and appropriately aligned with the research questions. To enhance reliability, an independent auditor reviewed the codes and themes [15]. These collaborative steps strengthened the trustworthiness of the findings and ensured that the analysis accurately reflected participants' experiences.

4.0 Findings

The findings align with the theoretical framework of teacher pedagogical beliefs, highlighting how pre-service teachers' reflections and experiences shape their instructional practices. Participants' narratives demonstrate the influence of outcome expectancies on their willingness to adopt innovative frameworks like EDP and CRP in their classrooms.

4.1 Beliefs

The experiential learning program significantly influenced participants' beliefs about the engineering design process (EDP) and culturally responsive pedagogy (CRP). Participants reflected on the importance of engaging students in real-world problem-solving through EDP. Ellie, for instance, noted how her confidence in explaining complex STEM concepts increased as she practiced simplifying ideas for students. She shared, "When I could help students connect to concepts through hands-on activities, their engagement and understanding grew exponentially." Sarah highlighted how the EDP facilitated critical thinking, sharing that a simple yet powerful activity like disassembling and analyzing a hairdryer helped students relate STEM concepts to everyday life. This approach empowered students to ask, "How does this actually work?" and deepened their curiosity about scientific processes. Similarly, Owen shared that using EDP provided his students with a framework for problem-solving, enabling them to actively explore solutions rather than passively absorbing content. In terms of CRP, participants described a transformative understanding of the value of relationships and cultural awareness in teaching. Ellie reflected on how understanding students' personal and cultural contexts shaped her approach, stating, "Every student has a unique story, and tapping into that builds trust and engagement." Owen echoed this, highlighting that CRP is grounded in relationship-building and an understanding of students' lived experiences. Sarah added that implementing CRP required "knowing your crowd," which involved learning about students' cultural contexts.

4.2 Practices

While participants had limited classroom experience to apply EDP beyond program activities, they demonstrated readiness and enthusiasm to integrate it into their teaching. Ellie expressed a need for more practical resources, noting, "With the right tools, I could see myself designing lesson plans that integrate engineering principles seamlessly." Owen shared his excitement about incorporating EDP in his chemistry lab, emphasizing how it fosters collaboration and problem-solving among students. CRP practices were more frequently discussed and applied during the program. For example, participants shared strategies for bridging language barriers, such as using visual aids and bilingual resources. Ellie suggested including side-by-side translations on slides, while Sarah emphasized the value of visual examples to support English learners. Beyond language, participants highlighted practices that centered students' cultural identities. Owen recounted how a field trip to students' communities broadened his perspective, helping him recognize and address blind spots in his teaching.

4.3 Approaches

The importance of humility and reflection emerged as a key theme in participants' teaching approaches. Sarah emphasized transparency, suggesting that acknowledging mistakes fosters trust and humanizes the teacher. Similarly, Owen described teaching as a continual learning process that requires flexibility and responsiveness to students' needs. Reflective practices were another essential approach. Owen shared a structured method of self-assessment, posing questions such as, "Are my lessons culturally relevant? Am I highlighting diverse scientists? Am I making the classroom welcoming and accessible?" This iterative process underscored the role of self-awareness in fostering inclusive and equitable STEM learning environments.

4.4 Positionality

The researchers acknowledge their positionality as it relates to this study, including their professional, personal, and cultural experiences, which shape the design, interpretation, and analysis of this work. As advocates for equitable STEM education, the researchers bring a commitment to addressing systemic barriers faced by underrepresented populations in STEM. Their work is informed by professional roles as educators and researchers at a minority-serving institution and personal experiences navigating educational spaces as individuals from historically marginalized backgrounds.

4.5 Limitations

This study has several limitations that should be considered when interpreting the findings. The small sample size restricts the generalizability of the results, as the experiences of participants, while valuable, may not fully represent broader populations of pre-service or in-service teachers. Additionally, the study is confined to a six-week summer program, which may limit its applicability to longer-term teacher preparation programs or different educational settings. Another limitation is the reliance on self-reported data, which, while useful for understanding teachers' beliefs, may not fully capture how these beliefs translate into classroom practice. Future research should incorporate classroom observations to triangulate findings and enhance validity.

Additionally, while some overlap was observed between instructional practices and teaching approaches, this work does not explore those complexities in depth. Investigating these nuances further could provide deeper insights into how pre-service teachers integrate EDP and CRP in instructional settings.

5.0 Implications

This study underscores the importance of experiential learning in preparing pre-service teachers to integrate engineering design (EDP) and culturally responsive pedagogy (CRP) into their instruction. Hands-on programs provide a practical foundation for student-centered, inclusive teaching. Teacher preparation programs should prioritize targeted training in EDP and CRP, develop culturally relevant engineering lesson plans, and offer mentorship from experienced educators to support pre-service teachers in applying these frameworks effectively. Engaging with students' communities is essential for culturally responsive teaching. Programs should create opportunities for teachers to connect with local communities, deepening their understanding of students’ lived experiences and strengthening teacher-student relationships. The intersection of EDP and CRP advances equity in STEM education by validating students' identities while fostering critical thinking and problem-solving skills.

Future research should explore the scalability and impact of these frameworks across diverse educational settings. Expanding sample sizes, incorporating classroom observations, and conducting longitudinal studies would provide deeper insights into how EDP and CRP shape instructional practices and student outcomes over time. Strengthening teacher preparation in these areas will ultimately foster equitable and engaging STEM learning environments.

6.0 Conclusions

This study highlights the importance of integrating engineering design (EDP) and culturally responsive pedagogy (CRP) into pre-service teacher preparation. Through experiential learning, participants gained confidence, refined their instructional beliefs, and developed inclusive, student-centered teaching practices. While challenges such as resource constraints and time limitations persist, the findings suggest that with targeted support, teacher preparation programs can effectively equip educators to navigate these complexities. Expanding access to experiential programs and conducting further research on long-term impacts and scalability will be crucial for fostering systemic change. By bridging the gap between theory and practice, these efforts can create a more equitable STEM education landscape, ensuring that all students see themselves reflected and valued in STEM learning environments.

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