A Reflective Evaluation of a Pre-College Engineering Curriculum to Promote Inclusion in Informal Learning Environments

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Introduction

Within the United States, pre-college (K-12) students spend approximately 80% of their day outside of school [1]. During the remaining 20% of their day, students in United States public schools spend the least amount of time receiving science-related instruction compared to reading and math [2]. In addition, other disciplines like technology and engineering may not be available to students during their school day. The accessibility and quality of science, technology, and engineering instruction depends on the school's available resources, which may position students from diverse racial, ethnic, and socioeconomic backgrounds at a disadvantage. As a result, out-of-school STEM programming often supplements the formal STEM education of many students.

While some STEM outreach programs have gained national recognition like Black Girls Code, NSBE's Summer Engineering Experience for Kids (SEEK), STEM NOLA, and INTech Camps for Girls to name a few, there are hundreds of STEM outreach programs targeting students from diverse racial, ethnic, and socioeconomic backgrounds. One goal of many of these programs is to increase the accessibility of STEM learning opportunities which promote students' development of skills, behaviors, and mindsets relevant to various STEM careers. Through students' participation, program leadership and researchers expect students to internalize attitudes and behaviors that can support a future career in STEM. As a result, the program design intends to define what it means to be STEM professional for the pre-college participants. By exposing diverse pre-college students to the field of engineering, the program design becomes a critical component of the STEM education ecosystem that defines who belongs and what counts in engineering education.

This paper uses critical reflection to challenge cultural ideologies commonly embedded in an informal engineering program. This paper includes critical reflections of two engineering education researchers about their experiences designing, facilitating, and refining a pre-college engineering summer camp intended for students from diverse racial, ethnic, socioeconomic, ability, and/or gender backgrounds. The reflections provide a structure to interrogate the cultural narratives about engineering embedded in the program design and transmitted to the students. The goal of this reflective practice is to understand the cultural narratives of engineering transmitted by the programming to students that may impact the inclusion of students from diverse backgrounds. In the remaining sections of the paper, we present an overview of the program design and explore embedded assumptions and manifested practices that define what it means to be an engineer.

Theoretical Framework

To examine the cultural narratives embedded in a pre-college engineering summer camp, we position our research through the theoretical lens of cultural production theory. Cultural production theory examines "local meaning(s) produced by groups in everyday practice, their

connection to larger social structures, and the possibility, no matter how slim of challenging the status quo" [3, p. 5]. By using the lens of cultural production theory, we can evaluate the ways individual and collective agency operate in the structural constraints of daily practice to construct culture [4]. Through this evaluation, we can identify the patterns in our actions (practices), the ways we label our efforts (intentions), and the ways we describe ourselves (histories) as production (e.g. alternative narratives) or reproductions (e.g. status quo) of cultural narratives [5]-[6].

In this study, we define culture as a dynamically shared set of meaning and patterns produced in daily practices [7]. As a result, we do not believe culture is a set of practices handed down from generation to generation [7]. However, the cultural ideologies embedded in the program design constrain the perspectives and actions of the staff and participants shaping what it means to be an engineer [7]. By analyzing the culture of engineering transmitted through the informal learning experience, we can interrogate privileged cultural narratives and refine normative practices to better support our programmatic goal to promote the inclusion of diverse students in engineering [3].

Overview of Pre-college Engineering Summer Camp

During the last three years, the Authors have partnered with a summer day-camp on our university's campus to offer a summer engineering makerspace experience for racially, ethnically, and socioeconomically diverse pre-college students. To take part in the camp, students must be in grades 3rd through 8th and live in households with gross incomes at or below the federal poverty guidelines [8]. For the first ten days, our team meet with the 3rd through 5th graders (n=140) in 45-minute periods throughout each day. For the last ten days, we then meet with the remaining students 6th through 8th graders (n=137) in the same format.

Curricular Structure

To support the camp experience, we categorize the program design into three main elements: the engineering-based curriculum, staff recruitment and training, and continuous improvement initiatives through concurrent design-based research. During the 45-minute period, we present students with design challenges constructed around the interests they identified on the first day of camp and support them in engaging in an engineering makerspace to prototype a solution for their design challenge. In this curricular structure, we encourage students to make connections between their current interests and engineering skills, behaviors, and mindsets [9]. By creating a program structure that uses human-centered design challenges in a makerspace environment, students use the engineering design process when working in teams to prototype and test solutions for societal problems they are most passionate about solving. By supporting students' personal interests through the engineering design challenges, we intend to show engineering as a diverse field that can appeal to the interests of anyone while encouraging student agency and exploration. In addition, we hope to promote a deeper engagement by creating counter-narratives to common engineering stereotypes.

Staff Recruitment & Training

As part of staff recruitment and training, we attempt to hire a diverse group of undergraduate and graduate students to lead the instruction and support student teams in the design process. Our

goal is to hire a staff representative of the camper population. Although this is not always possible. This past summer, our staff included four women and three men. These students identified as White (n=4), Latin@ (n=1), Asian descent (n =1), and two or more races (n=1). By hiring a diverse staff, we hope student can see themselves. By engaging camp participants with diverse staff members, we hope to challenge narratives about who belongs in engineering and students can envision themselves as engineers.

Besides portraying a racially, ethnically, and gender diverse staff, we also aim to show the diversity in engineering disciplinary backgrounds through our staff. For example, our staff included undergraduate and graduate students representing the following engineering disciplines: electrical, biomedical, industrial, mechanical, and chemical engineering. On the first day of camp, we introduce the staff to the students requesting they briefly describe their disciplinary expertise. We believe by highlighting the disciplinary knowledge of the staff, students can ask questions to individuals with specific disciplinary knowledge to advance their design and ask questions about disciplines of interests.

To support the camp initiatives, we provide the staff a series of training materials that includes readings, reflections, and discussions with returning staff members. We divide the training materials into two categories: instructional and research support. The training materials designed to support instruction includes overviews of the engineering design process, strategies for supporting students through their design challenges, and review of curriculum. The training materials to support our continuous improvement includes items about human subject research, research with minors, and the Authors' research philosophy and study protocols.

Continuous Improvement

The summer engineering makerspace experience is a design-based research project where the program undergoes iterative design, development, and test cycles each summer to improve the interventions effectiveness. Because of this continuous improvement process, our design-based research intends to achieve three objectives: (1) identify key elements of the intervention, (2) deepen the researcher's understanding of phenomena, and (3) uses prior research to describe and justify the intervention's design [10, 11]. We used the design-based research method to develop the engineering makerspace experience through a continuous improvement cycle that begins prior to the start of camp. During the academic year, we analyze student data (e.g. surveys, video recordings of design challenges, and interviews) along the plus/delta staff reflections from the previous year to identify curricular challenges and associated impact on our program goals. For example, our video data highlighted discrepancies in participation among team members. To help improve everyone's engagement in the learning experience, we discussed different options and settled on implementing team roles. This process continues as we refine the curriculum to prepare for the summer camp session. As we implement the curriculum during each camp session, we use daily student reflections and staff debriefs to capture what is going well, and any changes needed to better support student learning. Then at the conclusion of the camp cycle, we conduct a team debrief meeting and complete reflections to be used during analysis.

Methods

Expanding on the previous work, this paper uses critical reflections from two members of the research and instructional team as a method to evaluate how the program's design empowers

students from diverse racial, ethnic, socioeconomic, ability, and/or gender diverse backgrounds to find personally meaningful connections to engineering [10]-[13]. Critical reflection is the examination of ones' belief systems while intentionally evaluating the impact on practice [12]. By engaging in critical reflection, we aim to interrogate our beliefs to identify commonly held cultural ideologies (e.g. technocracy, meritocracy, de-political, and gendering) in engineering that manifest in our programming [12]-[19]. To engage in our reflective practice, we developed a set of guiding questions (Appendix A) that we individually answered as journal entries at the conclusion of the camp. After answering the guiding questions, we first coded our responses to identify our belief systems (intentions) [5]-[6]. Next, we coded the responses for how these intentions manifest in our curricular design (practices) [5]-[6]. Then we evaluated the cultural narratives created or reproduced by our privileged beliefs and the impact on our top three program goals to (1) illustrate the diversity of engineering, (2) engage students in human-centered activities that promote collaboration, and (3) nurture each students' potential to become an engineer.

Researchers' Positionality

Since critical reflection requires elements of self-reflection to interrogate ones' belief system, it is important for us to provide positionality statements as the foundation of our analytical perspectives.

Kayla

As a Graduate Assistant in Engineering Education, I focus my research on improving the culture of engineering to support the engagement of diverse learners. As a straight, cisgender, multiracial female, I recognize that although my racial and gender identities position me at the margins of engineering culture, my educational achievements provide opportunities to occupy positions of privilege. As a result, the aspects of engineering I value most are informed by my experiences as an industry professional, teacher, instructional designer, and engineering education researcher. I believe that the culture of engineering manifested in engineering learning environments can impact student success and if systematically investigated can be modified to improve access and retention of diverse students.

Morgan

As an Associate Professor of Engineering Education, I focus my research on introducing pre-college students to engineering through broad contexts to be inclusive of diverse student interests, backgrounds, and perspectives. I, myself, am a straight, cisgender, White male with a Bachelor's Degree in Mechanical Engineering and a Ph.D. in Engineering Education. Through my research work I have worked in diverse pre-college contexts and I am always impressed with the diverse solutions these many students come up with. However, I am dismayed with the lack of women and people of color pursuing engineering. As a member of the dominant culture of engineering, I see opportunities and have a sense of responsibility to enact change within this culture to be more inclusive of all learners.

Results

The purpose of this section is to present the evaluation of our top three program goals to demonstrate how critical reflection can be used to interrogate cultural ideologies embedded in program design. We present our top priorities in this section because we understand that it is

difficult to simultaneously change multiple program elements and evaluate the effectiveness of these changes. So, we encourage you to identify and prioritize your program objectives prior to making connections to your reflections to determine your continuous improvement efforts. To demonstrate how we engage in this process, we have divided the section into three parts representing our program goals. For each program goal, we outline how we intend for the objective to foster inclusion, the associated program design elements, the cultural ideologies produced (e.g. alternative narratives) or reproduced (e.g. status quo) by the design, and the resultant impact on broadening participation.

Diversity of Engineering

One of our program objectives is to highlight the diversity of engineering for the camp participants. By highlighting the diversity of engineering, we intend to expose students to a variety of industries engineers engage with to demonstrate how engineering can be connected to their interests. As a result, we want students to understand that engineering occurs beyond the stereotypical industries (e.g. automotive or aerospace). To support this goal, we use several design elements. First, we hire a staff from a variety of engineering backgrounds. On the first day of camp, we engage in staff introductions that include the staffs discipline expertise and short summary of their future career goals. Next, we conduct a presentation introducing students to engineering where we highlight engineers as people from different races, ethnicities, and genders. In this presentation, we also show engineering in non-traditional industries like music or theater. Next, we intentionally designed the curriculum to present the engineering design challenges as opportunities for students to tailor the learning experience to their interests. For example, we encourage students to redefine the problem statements to choose relevant social issues they encounter in their daily lives. In addition, the camp space is structured like a makerspace to promote engagement and exploration of affinity groups of individuals with similar interests.

Through these practices, we created a learning environment with a flexible structure to support students engaging as an engineering in multiple ways [21]. For example, when students redefine their problem statements and join affinity groups there may be five to ten different projects occurring at one time. To help provide structure, we provide a list of design tasks, like brainstorming, providing rationale for design decisions, or prototyping to be completed each day over the course of the week. The design task help guide students through engineering design process with their current idea. As a result of the redefinition process, students are able to create connections between engineering their interests and expertise. This challenges the cultural narrative that to be an engineer you must be intellectually elite and values the expertise and abilities of the students [21].

Despite our team actively creating a broad perspective of what it means to be an engineer, it does not always resonate with everyone. When creating affinity groups, students are asked to identify their top three interests. As a result, the pairing is not always precise. Sometimes students are placed on teams without their friends and/or on projects of their third interests. This can result in some students becoming disinterested in the design challenge. We currently do not have a pathway for these students to engage in the design challenge differently to promote re-engagement. Therefore, our attempt to help students make connections between their interests and engineering is not always as effective as we intend. To improve our programming, our team

could provide alternative pathways for engagement by allowing students to operate in a variety of different roles engineer may fulfill. For example, students interested in media could engage in the design process by creating a marketing campaign for the teams' solution. This would facilitate the students' re-engagement with the activity, improve the alignment of the design challenge with their interests, and further support ways of being an engineer that transcends stereotypical avenues.

Human-centered design challenges that promote collaboration

Despite our team actively trying to highlight a broad perspective of what it means to be an engineer, we recognize that some design elements we incorporate reproduce the status quo. For example, the narrative that engineers fix or build things is perpetuated through the structure of our design challenges. At the conclusion of the camp duration, we expect students to have a physical prototype of their solution. When critically reflecting on normative practices of the program design, Morgan described the curriculum as

> hands-on, creative, focuses on problem-solving for people, and is team-based. Some norms that may be implied through the curriculum include: engineering is done in teams, engineers make things, engineers help people, engineers test, engineers learn from failure, and engineers solve problems.

In Kayla's reflections, she echoed similar norms. Although these practices reflect, potentially obvious, expectations of an engineering intervention, the structure of the activities in the makerspace embed a lot of assumptions about the "ideal" or "successful" camp participant. As a result, the human centered design challenges in teams reproduces cultural narratives that privileges students' technical competencies and work ethic [21].

Although this reproduction does not inherently have a negative impact on the inclusion of students, in the context of our camp it results in who is recognized as successful. This reproduction privileges students with who have a high self-efficacy for building things. As a result, through our critical reflections, we discovered that we are missing an opportunity to promote the inclusion of students who may have diverse physical or cognitive abilities. In our continuous improvement efforts, we do not foresee us removing the human-centered design challenges in our future camps, but we do want to explore alternative ways for students to communicate their designs beyond building physical prototypes. By facilitating student engagement in this way, we can also further support our program objective of demonstrating other ways students can engage as an engineer.

Everyone can become an engineer

By promoting the diversity of engineering through human-centered design challenges that foster collaboration, we intend to value each campers' potential and support their interests in engineering as a future career pathway. By valuing each campers' potential through their interests, we intend to demonstrate to students that anyone can become an engineer. Through our human-centered design challenges, we hope to produce a cultural narrative that supports students who may not identify with stereotypical attributes of an engineering like "being good at math or science", "nerd", "not creative", "loners", or "social activists" to engage with engineering [21]. But as previously stated, this does not always resonate with students in the ways we intend. For

example, in our critical reflections we found that we recognize students with high self-efficacy for building prototypes. This ultimately emphasizes that engineers build things, which limits the pathways students may feel recognized during the design process. As a result, we noticed that our design sometimes has competing priorities. For example, when our reflections were triangulated with student data, the emphasis on building manifested as a component of the camp that created the most doubt amongst our campers initially. Often students discussed their uncertainty due to unfamiliarity. However, we noticed over the course of the camp this often improves as students are introduced to new tools and the ways to use them to design a solution to their passion project. Despite this often become a positive production, we are continually balancing the elements of the camp to best support students understanding that our productions and reproductions holistically can promote and hinder students' inclusion.

Discussion

Through our exploration of the cultural productions embedded in our summer engineering experience, we identified our intentions, practices, and program objectives that facilitate or hinder the inclusion of students from diverse backgrounds. By using the analytical lens of cultural production theory to evaluate our critical reflections of the program, we learned that despite our best intentions we have design elements that support cultural narratives of engineering that are not historically recognized for students from diverse backgrounds. On the other hand, we also discovered that some of our design elements creates competing priorities that can hinder students' inclusion. As a result, our critical reflections demonstrate that program design is a continue balancing act that requires continuous evaluation of program goals, our practices, and the impact on ultimate goals to improve the inclusion of diverse students. By using reflection prompts from Appendix A, we hope that program designers have a tool to help them critically evaluate how their program design meets their intentions of encourages the inclusion of target student populations.

Acknowledgements

This material is based upon work supported by National Science Foundation under Grant No. CAREER-EEC-1454152. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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Appendix A – Guiding Questions

1. *What norms, behaviors, or perspectives of engineering did you want the curriculum to value?*
2. *What elements of the curriculum were used to communicate these norms, behaviors, and perspectives to students?*
3. *Why were these norms, behaviors, or perspectives important?*
4. *In practice, what norms, behaviors or perspectives of engineering are valued by the curricular design?*
5. *How do the norms, behaviors, or perspectives manifest in the curriculum?*
6. *What gaps exist between what we intended and what is valued in the curriculum?*
7. *Describe the camper you imagined when designing the curriculum. What assumptions did you make about this camper?*
8. *How does our image of the ideal camper influence the norms, behaviors, and perspectives valued by the curriculum?*
9. *How does the image of the ideal camper influence the way the norms, behaviors, and perspective manifest in the curriculum?*
10. *What norms, behaviors, or perspectives is not explicitly valued through the curriculum, but should be incorporated? Why?*