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Bridging Formal and Informal Learning: Linking Classroom and Museum Experiences in Engineering Education

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Introduction

Interactive science museums offer valuable spaces for young people to explore science and engineering beyond the classroom. At their best, these institutions can deliver engaging engineering experiences that align with and extend students' learning in formal school environments and support district and state-level curricular objectives [1]. However, connections between informal learning experiences and classroom instruction remain uncommon, with such opportunities seldom embedded within standard curricula. In efforts to maximize learning outcomes for field trip experiences [2] and provide support for teachers teaching engineering [3], [4], we used design-based research methods to create an engineering-design curricular program that linked field trip learning to the classroom via pre and post field trip classroom activities.

In this paper, we sought to understand the impact of this curricular model on teachers' perception of integrating engineering education into their teaching practice and its attendant impacts on student learning. We asked two research questions:

1. How do teachers perceive an engineering education experience for elementary students that spans formal and informal education spaces with regards to their *teaching practice*?
2. How do teachers perceive an engineering education experience for elementary students that spans formal and informal education spaces with regards to *student learning*?

Using qualitative data analysis of interviews with 11 teachers engaged in the program, we demonstrate how bridging formal and informal learning environments can support student understanding of the engineering design process and strengthen professional skills such as communication and a growth mindset. We argue that teachers can benefit from an increased capacity to teach engineering in creative and novel ways by bridging community resources to classrooms in ways that support early engineering education. This work contributes to our understanding of how extending field trip learning into the classroom benefits teacher and student outcomes, while also highlighting key areas for future research to support these networked efforts.

Theoretical Framing

This work is rooted in the theoretical perspectives of two domains: informal science education and teacher preparation for early and pre-college engineering education.

First, informal science education (ISE) is a growing field of scholarship which recognizes the boundary-spanning nature of learning [5], [6], [7]. Informal learning is often characterized by its voluntary nature that is guided by learner interests in a nonlinear and open-ended fashion [1]. ISE scholarship examines how learning happens in and across contexts such as science museums [8], afterschool programs [9], the home [10], and other spaces where learners encounter disciplinary content or ideas. Informal learning, broadly, and ISE, specifically, is an important strategy for addressing inequities in STEM education [1], [11]. Some argue that informal education environments, such as science museums, can broaden participation in STEM by supporting interest and motivation in these disciplines because informal contexts prioritize free-choice and visitor-centered learning experiences that appeal to wider audiences [12]. Others argue that informal learning is a critical strategy for addressing inequities because it builds on the assets of individuals and communities as they engage in culturally relevant practices [13].

The adoption of the NGSS standards and broader science education reforms formally added engineering to the early education curriculum [14]. This created new challenges and opportunities for educators to design curricula for students across the early grades that prepares them for future learning while being developmentally appropriate and authentic to the practices of engineering. Teachers report an array of barriers to successfully integrating engineering into their early education classrooms; these range from practical constraints such as availability of materials or time to lacking self-efficacy in teaching engineering [15]. As an example of significant ways teachers must shift their thinking when teaching engineering, consider the idea of "failure." While teachers strive to facilitate student success, failure is a normal and essential part of the engineering design process. Confronting failure in their own practice and in students' learning process is a challenge for educators in trying to authentically integrate engineering learning into their classroom [16].

Student field trips and teacher professional development programs led by science centers and museums lie at the nexus of the fields of informal science education and engineering education. Field trips are one of the oldest established strategies for connecting students to ISE contexts. However, the evidence of the impact of field trips is mixed [17], [18], and often teachers do not have explicit goals for their visit [19], or are unaware of their role in shaping student experiences during field trips [2]. Additionally, we must acknowledge that there are significant barriers to accessing science museums such as high ticket prices [20], [21] and cultural barriers [22], [23]

To address challenges in pre-college engineering education with the affordances of informal science education, we developed a curriculum model that aimed to provide a high-quality, integrated engineering education experience while supporting teacher's professional learning around engineering education. This model, described in further detail below, supports extended goal-oriented learning across classroom and museum spaces by connecting pre- and post-field trip classroom activities to a field trip to a local science museum. By providing curricular structures, this program supported more varied engagement with engineering at the pre-college level [24], [25] that also increased student opportunities for engineering communication [26]. While the program was designed to support teacher and student learning, this paper explores teacher perceptions of their participation in the program and students' learning. Understanding how a cross-institutional curricular module impacts teaching practice and student learning is important when working towards bridging the gap between pre-college engineering and informal science learning spaces. We describe the program context, and the specific unit we studied for this paper, in the next section.

Program Context

This program, called Explore Engineering, was developed through a Research-Practice Partnership [22] between a large R1 university and the local interactive science museum. Together we developed a model for bridging classroom and field trip learning through 4-part curricular modules. Each module centered around an engineering design challenge and supported structured engagement with the engineering design process across time and learning contexts. Each Explore Engineering module consisted of two teacher-facilitated pre-field trip activities that took place in the regular classroom, a field trip to the local interactive science museum, and a teacher-facilitated post-field trip activity that reflected on the previous three activities. This four-part structure was designed to scaffold student learning, build direct connections between classroom and museum learning, and provide opportunities for teachers to learn about engineering education. Design based research methods guided the iterative development of program materials [28] (for more information about the program development process, see [29]). The two modules focused on in this paper centered around (1) designing an apparatus that altered the rate of descent of a small object such as a washer and (2) designing a protective covering for a greenhouse on the moon that optimized light and thermal energy penetration. For more information about these modules, see [25] and [29] respectively.

Methods

To understand teacher perceptions of how the interaction between the field trips and their classroom space affected students and teachers, we interviewed 11 elementary classroom teachers who participated in our full program using a semi-structured interview protocol [30] to understand their views of the success of the program, learning outcomes for themselves and their students, and their perception of the connection between the classroom and field trip. There were two first grade, three third grade, one fourth grade, one fourth-fifth grade combo, two fifth grade, and two sixth grade teachers. Teachers were interviewed before and after the completion of the full module. Four teachers observed museum educators facilitating the classroom activities and museum field trips during early testing of the program and seven teachers facilitated the classroom activities themselves and attended the field trip program with their students. In addition, we captured field observations [31], [32] throughout the full modules.

Two researchers (first and second author) who captured field observations thematically analyzed the post interviews with classroom teachers to identify emergent themes across all teachers for their perceptions of teacher pedagogical practices and student learning when engaging in a cross-institutional engineering curricular module. Once we reached consensus on the emergent themes, we discussed how these themes were or were not reflected in our field experiences working with the teachers. Using our final list of emergent themes, we then identified two teachers who represented the diversity of teaching experiences with one having observed researchers implement the curriculum and one teaching the materials themselves while highlighting the salient themes.

To illuminate how teachers experienced and made sense of an engineering curricular program that bridged classroom and museum learning environments, we present two illustrative vignettes. Vignettes, short stories that present specific instances from the data, are used in qualitative research to foreground participants' perspectives while situating their experiences within the broader analytic themes of a study [33]. Rather than serving as comprehensive case studies, these vignettes are intentionally selective and analytic, highlighting moments that exemplify how teachers interpreted alignment across learning contexts and how they observed students engaging with the engineering design process. Each vignette weaves together interview excerpts, classroom observations, and the teachers' reflections on the multi-part curricular structure, including pre-field trip classroom activities, the museum field trip, and post-field trip reflection.

Findings

This study aimed to understand how teachers perceive an engineering education experience for elementary students that spans formal and informal education spaces with regards to (a) their *teaching practice* and (b) *student learning.* Thematic analysis of interviews with 11 teachers and observations noted above surfaced two key findings concerning teaching practice and one theme concerning student learning. First, we found that intentional instructional practices are necessary to resolve epistemic tensions between formal and informal learning environments, as well as between dominant classroom cultures and the tenets of engineering design (Theme 1: Intentional instructional practices). Second, we found that institutional constraints are barriers to engineering education, but that educators can effectively respond to material, financial, and temporal limitations by modeling engineering design practices (Theme 2: Institutional constraints). For the second research question, we found that establishing a culture of engineering design across contexts supports student learning (Theme 3: Establishing a culture of engineering across contexts). By positioning engineering as a process that unfolds over time and across learning environments, teachers perceived students as being appropriately and authentically engaged in engineering design.

While these emergent themes were identified across all 11 participants, this program and teachers' engagement with the four-part module is highly context dependent. Therefore, we selected two teachers–Lisa and Jack–who were purposefully selected to reflect variation in teaching experience, familiarity with engineering, and classroom context to write complete vignettes of their experiences, to illustrate how our three emergent themes played out across institutions and time. The vignettes provide concrete examples of how these teachers navigated tensions between traditional classroom norms and the epistemic practices of engineering design, such as iteration, failure, and collaborative problem solving; how they addressed logistical constraints; and what they perceived as supportive of student learning. In doing so, they offer portraits of how these themes, which emerged from the full data set of 11 teachers, were experienced by individuals making sense of their practices around pre college engineering education.

Table 1: Characteristics of teachers and classrooms in illustrative vignettes.

	Teaching Experience	**Familiarity with Engineering**	**Classroom Context**	**Explore Engineering Facilitation**
Lisa	Six years teaching early elementary general education.	Limited professional development on engineering education. Partnered with local indigenous nation to facilitate an engineering project with students one time.	"River School" 3rd grade classroom. Newly opened elementary school focused on interdisciplinary learning and STEM.	Pre-and post-field trip lesson plans implemented by Lisa
Jack	Two years teaching early elementary general education.	Engineering undergraduate degree. Some prior experience leading engineering activities with students.	"Lemon School" 1st grade classroom. Jack is piloting a new science curriculum in his classroom.	Pre- and post-field trip lesson plans implemented by science center educator; Jack observed lessons.

Pausing to Build Norms in Lisa's 3rd Grade Classroom

Lisa had been teaching 3rd grade in the River School District for 6 years, but the year of the study was her first year teaching at the brand new Elementary school that focused on interdisciplinary approaches to learning. This transition meant she was engaging in a lot of professional development around STEM elementary education and pedagogical approaches. In her classroom, students engaged in an engineering project through a partnership with the local indigenous nation where students learned the history of the design of the Tomol (long boats traditionally used by the indigenous nation) and developed their own Tomol prototypes. When reflecting on her experiences with engineering prior to participating in the Explore Engineering curriculum development project, she shared that engineering was, "actually something that is fairly new to me. So I don't necessarily say that I'm teaching it, I always say that I'm learning it with them. Because, my school experience was very much, like, sit down at the table, do your work. And the exploration wasn't there when I was younger. So I don't say that I'm teaching, I just say that I'm learning right beside them and that's exactly what I'm doing" (Theme 1: Intentional instructional practices).

Prior to the lesson, Lisa struggled to obtain the supplies that the activities called for. For example, she didn't have deli paper or washers in her classroom, but attempted the lesson with other materials (tissue paper and pennies; Theme 2: Institutional constraints). After testing the alternative materials herself, she found time in her schedule to purchase the full materials which she felt worked better to demonstrate the desired phenomenon students were engaging with. Even though she eventually sourced the recommended materials, Lisa's effort to identify alternatives prompted the curriculum development team to list other materials that might be more readily available for teachers to prepare for the lessons.

During the pre-field trip activities, Lisa spent a lot of time working with students on how to collaborate and communicate, even when they were frustrated (Theme 1: Intentional instructional practices). When tensions rose in the classroom as students encountered failure, she paused the lesson to have a discussion about how to handle frustrations and learn from failures to improve future designs. She described that in these moments, “we really spent time on talking with our partners that we were working with because if everyone is talking at once then it is hard to accomplish a task. So that was really awesome. So for the first [pre-field trip activity in the module] it was really like setting the foundation for how we collaborate together, and so we took the time with that.”

Lisa perceived that her intentional work to develop communication and socio-emotional skills with students helped them be successful during the engineering design challenge at the science center (Theme 3: Establishing a culture of engineering across contexts). She noted that students demonstrated a willingness to iterate and build off of failure. She reflected on the field trip, “That was truly wonderful because in the class… we talked about communication and collaboration, and we talked about what happens when we get frustrated, so by that time when we actually went to the [the science center] they were having so much fun with it. And they were like, ‘Oop it didn’t work’ then they went back inside and tried to fix [what went wrong] but it was never like the negative mentality of ‘Aw man I can’t do this,’ they were so excited and so joyful because we laid that foundation of we’re just trying and we’re just trying to test out what would and wouldn’t work. For them, for that one, it was just joy.”

After Lisa and her students completed the full module, she reflected on her comfort engaging with the materials and stated, “I felt comfortable with it. I did have to read it a few times to understand it, but once I read through it fully, I mean everything is right there for us–it just takes time to read through it and understand, but it wasn’t difficult at all” (Theme 2: Institutional constraints). She also shared how she embraced a fail-forward mentality, that is, a willingness to learn from one’s mistakes, in her teaching to model this behavior for her students (Theme 1: Intentional instructional practice). She remarked, "if the educator is willing to learn...and trying and failing themselves, then it translates over to the students, right?" Overall, she shared that this experience was shifting how she positions herself within the classroom space stating, “I think the biggest take away is me learning alongside them and me not being a sage on the stage, like me just kind of learning with them because I think that sets the tone of ‘I don’t have the answers and I'm willing to learn alongside them.’ I think that is a really big one. I think that’s really important to engineering is being able to try something, change it, manipulate it to try again, and what you’re learning each time you go through different processes.”

Prioritizing Process in Jack’s 1st Grade Classroom

Jack was a second year teacher of 1st grade at Lemon Elementary. He studied architecture and civil engineering in college prior to receiving his teaching credential. At Lemon Elementary, there was no specific science curriculum that had been adopted and Jack was tasked with piloting a science curriculum the school was considering in his classroom. Prior to the Explore

Engineering program, Jack's students had done a few engineering activities such as toothpick apple rafts and building bridges to hold pennies. For these projects, Jack used a two-step iteration process in his engineering lessons with the first iteration being student-driven, open-ended exploration followed by a discussion about iterative improvement. The second iteration involved students improving their designs. With regards to teaching engineering, Jack rated himself a three-and-a-half out of five comfort level and shared that he thought students are, "able to accomplish a lot [in engineering]. I don't think they get enough credit for their ability to think through problems. I am amazed at the answers that they give me when I pose engineering questions to them. Mainly it's vocabulary that they really need in order to solve it. They may have an idea but have a tough time describing what they want to say" (Theme 1: Intentional instructional practices).

During the classroom activities, the lead museum facilitator led the activities while Jack circulated around the classroom to support students during tasks. Small groups each had the support of a museum or research staff member when engaging in the pre-activities. When reflecting on the curricular module, Jack highlighted how his students benefited from learning and implementing the engineering design process with iterative development (Theme 1: Intentional instructional practice). He remarked, "I think it went really well. Kids were engaged, they got exposure to things that they may not have before, especially as far as trying to improve upon something that they previously had started working on or their ideas that they had. That's not something that they do too much of. Usually they have something they do, it's a product, they finish it and they move on, but to keep on going back and trying to refine their ideas with what they're learning, I think that's a great experience for them." This success with learning and engaging with the engineering design process was helped by the classroom norm Jack had previously established with his students around a growth mindset (Theme 3: Establishing a culture of engineering across contexts). He shared, "In my room, making mistakes are [sic] celebrated with brain growth so you want to make those mistakes…So I think that they were very receptive towards that because I've already primed them on making mistakes." For Jack, the understanding of the iterative design process was the biggest takeaway for his students from this curricular module.

As an instructor, observing his students participate in this engineering module challenged Jack's views of both engineering and how to run engineering activities in his own classroom. When asked about how his own perceptions of engineering had shifted through participation, he shared, "You know actually, the focus on the process. I mean I knew about that before, but just that being kind of the, that's the lesson. I mean I went to this engineering college and I don't think that was promoted as much as you guys [the museum educators] promoted it, which I think is the most important part of trying to accomplish, not the actual designs but the process of coming to some sort of design. I think that that's probably the biggest thing." Seeing this shift in curricular focus away from output and more on the design process influenced his perceptions of his own classroom teaching of engineering.

He commented on how allowing students to openly explore and test their iterations was somewhat uncomfortable and chaotic, and yet he saw value in that chaos for student learning (Theme 3: Establishing a culture of engineering across contexts). Seeing how effective open-ended iterative design was for his students, he shared how he wanted to shift his own classroom practices to allow for more student-driven learning (Theme 1: Intentional instructional practices). He stated, “I’m going to be trying that out too, to let go instead of the constraints or of taking away the choice, instead giving them as much choice as possible and then seeing where it goes. And then start letting them come up to the conclusion as we go along and then maybe fill them in at the end of what has already been done, you know what someone else has already done. Maybe even not.” Despite a desire to increase the amount of open-ended design activities he brings into his classroom, Jack did express concerns around the time needed to prepare so many materials for students, especially first-graders who required additional support as they developed their fine motor skills (Theme 2: Institutional constraints).

Themes Represented in Vignettes

The purpose of this study was to examine how elementary teachers experienced and interpreted an engineering curricular program that intentionally bridged classroom and museum learning environments, with particular attention to teachers’ pedagogical practices and student learning. The two vignettes presented—Lisa and Jack—illustrate how teachers with differing backgrounds, levels of engineering familiarity, and classroom contexts navigated this cross-context curricular experience. Together, these cases illustrate perspectives from a larger data set of interviews with 11 teachers who participated in the Explore Engineering curriculum development project. Lisa and Jack’s reflections show how the project challenged these teachers to negotiate tensions between formal and informal learning contexts, as well as tensions between classroom teaching and principles of engineering design. They did this by utilizing intentional instructional strategies that supported students and shifted their own positioning in the teacher-student relationship, even when they encountered logistical constraints. They show how student growth in early engineering education was supported when teachers conceptualized engineering as a process that carries across learning environments, as from the classroom to the museum. We discuss these themes in more detail next while bringing in the voices of other teachers who participated in the research.

RQ1: How do teachers perceive an engineering education experience for elementary students that spans formal and informal education spaces with regards to their *teaching practice*?

Theme 1: Intentional instructional practices are necessary to resolve epistemic tensions. Teachers had to actively engage in instructional practices to address tensions between the norms of formal classroom teaching/learning and the epistemic practices emphasized within the engineering education experience. Traditional classroom cultures often follow structured activities where students seek the “right” answer and complete high stakes assessments while positioning teachers as the primary authority and students as recipients of knowledge. Third grade teacher, Ciara, spelled out this tension plainly: “I think that some teachers might want to, you know, like give the right answer, like ‘this is the design, this is the way it has to be,’” and that, “in a lot of environments in schools [students] don’t get that opportunity.” In contrast, the engineering design process foregrounds iteration, uncertainty, productive failure, and learner agency. Teachers grappled with this tension as they supported students through open-ended, and at times messy, design activities.

Several teachers reported how the Explore Engineering experience prompted an intentional shift in their pedagogical stance which ultimately supported student outcomes. Third grade teacher

Katherine reflected on a lesson plan where students consistently designed ineffective solutions but she chose not to "tell them it was wrong, I just kind of let them go with it and then we had a good conversation…So I sort of improvised a little bit." Lisa consciously identified herself as a learner alongside her students by embracing a "fail-forward" mentality that challenged conventional classroom expectations around control and correctness. Additionally, she carved out time in the pre-field trip classroom activities to establish norms around collaboration, communication, and managing frustration, which enabled students to engage joyfully and persistently during the engineering program at the science center. For Jack, he experienced a discontinuity between his own background in engineering and the practices modeled by museum educators. Through the module, Jack recognized that prior engineering experiences—both in his own education and in his classroom—had often emphasized products over process to the detriment of student learning. In his case, observing how the museum facilitators prioritized iterative design reinforced the value of allowing students to explore, revise, and reflect, even when this resulted in apparent chaos.

These elements of teachers' experiences suggest that when classroom instruction explicitly prepares students for the epistemic norms of engineering, the transition to learning environments where iteration and failure are normalized can feel seamless rather than disorienting. This also suggests that teachers with diverse backgrounds will have varying levels of comfort in making shifts in their teaching practice to support engineering education. From specific strategies for discussing collaboration to holistic reframes of their stance and role in the classroom, there is a need for professional development and support to prepare teachers for effective engineering instruction. Jack's reflections indicate one potential strategy for support: observing informal educators in the practice of pre-college engineering education can support teachers in shifting their perspectives on engineering instruction. Communicating and modeling an engineering mindset that normalizes messiness, iteration, and uncertainty may help teachers reframe what counts as meaningful engineering learning–and quality teaching of engineering.

Theme 2: Institutional Constraints Around Engineering Education Can be Met with Engineering Design. While teachers in this program valued the pedagogical potential of engineering design, they expressed challenges with material, temporal, and cultural constraints on implementing engineering curricula. Both Lisa and Jack, like their peers in the wider data set, raised practical concerns about time, materials, and students' developmental readiness to engage in engineering design. Another teacher, Tessa, reflected on the faults of the program, noting that, "I did [the follow up activity] too far out, I should have done this right when we got back, but I had a lot of things going on I couldn't get to it," which interfered with student learning. Tessa was also sensitive to different teachers' attitudes around engineering, suggesting that we design curriculum materials that accommodate "old school teachers…who are going to look at the whole packets and say 'That's too long, I don't have time.'" Similarly, fourth grade teacher Jessie reported that the post-lesson, co-taught with another teacher's class, was compromised by too many students and not enough time in the activity, which, in accordance with Theme 3, was hard to balance with the desire to create opportunities for students to iterate because for the teacher, "it's definitely a building, layering going on."

These comments underscore how logistical and institutional constraints–and the momentum of historical practices–shape teachers' willingness and ability to enact instructional approaches that are authentically aligned with the engineering design process. This finding suggests that curriculum must be sensitive to these limitations and offer multiple options for implementation. This was the case when Lisa shared how she embraced an engineering mindset to source alternative, more accessible materials for a pre-field trip activity. As such, professional development for early engineering education can serve the dual-purpose of introducing engineering design principles to teachers and explicitly supporting them in embracing engineering design strategies to find solutions to the classroom realities in their local context which might otherwise impede engineering education.

RQ2: How do teachers perceive an engineering education experience for elementary students that spans formal and informal education spaces with regards to *student learning*?

Theme 3: Establishing a Culture of Engineering Design Across Contexts Supports Student Learning. Teachers consistently described growth in students' engagement, confidence, and participation in engineering practices as a result of the formal-informal curricular experience. Rather than viewing engineering as a one-time activity or a final product, students interacted with engineering design as an ongoing process that unfolded across classroom lessons and the museum field trip. This sustained engagement allowed students to revisit ideas, communicate design decisions, and apply learning from one context to another.

Lisa observed that her students' willingness to persist through failure and collaboratively refine their designs was a direct outcome of the norms established prior to the field trip. The continuity between settings reinforced students' understanding that iteration was expected and valued. Similarly, Jack noted that students benefited from repeated opportunities to improve their designs, an experience that contrasted with typical classroom tasks that emphasize completion over refinement. Sixth grade teacher Lillian, said, "I think that it is meaningful when you put the whole thing together," including the museum visit, even though engineering, for her, was "already a hard subject to get in in the first place." Teachers also highlighted how movement between contexts created authentic opportunities for students to articulate their thinking, strengthening communication skills as they explained prior work to museum staff and peers.

Importantly, teacher reflections on this engineering education experience suggest that focusing on the engineering design process—rather than technical mastery or final artifacts—is an appropriate and meaningful outcome for elementary level students. As veteran first grade teacher April commented, "I was very impressed with the level that they brought it down to to teach first graders…really thinking about what they could do to change their designs. They loved it." Students demonstrated increased comfort engaging in engineering practices such as testing, revising, and problem-solving, even when they lacked the technical vocabulary to fully articulate their ideas. Students benefitted from a structure that prompted them to engage over time in authentic engineering problems, as was the case in the Explore Engineering program. Conceptualizing the engineering design process as a developmental practice, rather than as content to be mastered, was a throughline from classroom to museum and back again. This perspective, plus an effort to establish a culture of engineering design that embraced failure, collaboration, and problem-solving, supported student learning.

Discussion

In this paper, we explored how teachers perceive an engineering education experience for elementary students that spans formal and informal education spaces with regards to their teaching practice and student learning. Using semi-structured interviews with 11 classroom teachers who participated in an Explore Engineering module, we identified three emergent themes from all teachers with regards to their teaching practices and student learning. Using descriptive vignettes, we highlighted how these themes presented themselves within the classroom spaces for two teachers who represented different career lengths, type of involvement in the modules, and different schools.

We found that intentional instructional practices are necessary to resolve epistemic tensions between traditional classroom learning and the epistemic practices used in the Explore Engineering modules. Formal classroom instruction and informal learning, such as what takes place at a museum, often are perceived as conflicting approaches to teaching and learning [34]; however, the Explore Engineering modules were designed to embody best practices within both while centering the engineering principles of failure, iterations, and messiness. Teachers commented that modelling fail-forward mentalities, establishing communication norms early on, and embracing messy iterative development helped students succeed and bridged the gap between their classroom and the museum. The second emergent theme, that institutional constraints around engineering education can be met with engineering design, indicates that teachers can overcome institutional barriers such as time and material limitations by leveraging the flexibility of the engineering design process in their own teaching practice. Lastly, by establishing a culture of engineering design across contexts, students are better able to engage with and learn engineering design. These findings have implications for those designing pre college engineering experiences. By considering how teachers are being supported through curriculum design and professional development, researchers can foster an engineering mindset and help teachers overcome institutional and epistemic barriers to cross-institutional engineering programs. Additionally, students benefit from cross-institutional learning where they can apply similar knowledge in novel environments. By designing engineering curricula to foster this transfer of knowledge, we can deepen understanding of engineering for students.

This study, while providing insights into teacher perceptions of teaching practices and student learning, does have some limitations and future research directions to further this work. Firstly, interviews present biases of self-report. Future work would benefit from comparing interview findings to observations of the classroom and field trip experiences to validate the findings further. Additionally, this work took place in central California with two schools that prioritize STEM learning and who have access to a local science center. As such, additional studies should be done in different geographic locations with a variety of schools and contexts for informal learning.

Taken together, these findings demonstrate that this model for engineering education curriculum that spans learning environments can support teacher pedagogical growth and student engagement with core engineering practices. Purposefully designed curricular materials that span classroom and informal learning environments help teachers envision what engineering can look like in early childhood settings while providing students with authentic opportunities to engage in iterative design. However, for such programs to be sustainable, future efforts must address teachers' perceived logistical constraints and provide targeted support for integrating engineering mindsets into existing classroom structures.

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