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The Role of Teacher Feedback in Shaping the Curriculum of a Pre-College Engineering Program (Evaluation)

Dr. Medha Dalal, Arizona State University

Medha Dalal, Ph.D., is an Associate Director of Scholarly Initiatives and Assistant Research Professor of Engineering Education Systems & Design within the Ira A. Fulton Schools of Engineering at Arizona State University. Her career as an engineering educator and researcher focuses on addressing complex engineering education challenges by building capacity for stakeholders at the grassroots, while also informing policy. Specifically, her research seeks to transform and democratize engineering education by exploring ways of thinking, identifying effective professional development approaches, and uncovering pedagogical techniques to enhance students' engineering curiosity, engagement, and learning.

Dr. Cathy P. Lachapelle, STEM Education Insights

Cathy is particularly interested in how collaborative interaction and scaffolded experiences with disciplinary practices help children learn science, math, and engineering. Her work on STEM education research projects includes design, evaluation, and effi

Dr. Kenneth Reid, University of Indianapolis

Kenneth Reid is the Associate Dean and Director of Engineering at the R. B. Annis School of Engineering at the University of Indianapolis. He and his coauthors were awarded the Wickenden award (Journal of Engineering Education, 2014) and Best Paper award, Educational Research and Methods Division (ASEE, 2014). He was awarded an IEEE-USA Professional Achievement Award (2013) for designing the B.S. degree in Engineering Education. He is a co-PI on the "Engineering for Us All" (e4usa) project to develop a high school engineering course "for all". He is active in engineering within K-12, (Technology Student Association Board of Directors) and has written multiple texts in Engineering, Mathematics and Digital Electronics. He earned a PhD in Engineering Education from Purdue University, is a Senior Member of IEEE, on the Board of Governors of the IEEE Education Society, and a Member of Tau Beta Pi.

Vedika Vinayak

Dr. Katie McKeown, Engineering for US All (e4usa™)

Dr. Katie McKeown works for Engineering for US All (e4usa™), 501(c)(3), as the Business Operations Coordinator and Director of Assessments after four years of supporting e4usa alongside her graduate school work. She is passionate about low-income and first-generation college student and STEM education experiences. She currently works in these areas as co-founder/board member of Duke First, founder/director of Packs of Hope, 501(c)(3), and a mentor in different education spaces. Dr. McKeown graduated with a Ph.D. and Masters in Mathematics from the University of Alabama and her A.B. in Mathematics from Duke University.

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Abstract: The demand for engineering professionals has fueled an expansion in pre-college engineering education programs in recent years. Despite their proliferation, there is a significant lack of comprehensive understanding regarding the evolutionary dynamics of these curricula over time. Existing research has predominantly focused on student perceptions, teacher beliefs, and general program evaluations, often overlooking how curricula respond and adapt to the specific needs and experiences of teachers and students. This paper explores the evolution of a pre-college engineering curriculum, drawing on evaluative data over the years from participating teachers. The methods and results highlight how teacher feedback has shaped the curriculum's components, including lessons, activities, student materials, and teaching guides, thereby enhancing the effectiveness of the course. This iterative refinement, grounded in real classroom feedback, not only demonstrates the program's commitment to responsive curriculum design but also provides valuable insights that could influence future pre-college engineering education development efforts.

Introduction

Over the last two decades, multiple reports have reiterated and expanded upon the necessity for a genuine and effective introduction of engineering in K-12 education, aiming not only to mitigate the ongoing shortage of engineers but also to enhance technological literacy across the U.S. [1-4]. Despite the increase in demand for pre-engineering programs in K-12, difficulties remain in implementing these programs, such as a lack of educational standards, lack of engineering in teacher education and training programs, and continuing issues with broader citizenry around and outspread participation in engineering [3-5]. Publications like the National Academies' "Engineering in K-12 Education: Understanding the Status and Improving the Prospects" [6] have also highlighted the critical importance and the challenges of integrating engineering concepts into the K-12 curriculum effectively.

Curriculum development is a complex process that involves creating a new curriculum through multiple implementation evaluations and iterations to produce a course of study or a program that provides quality teaching and learning conditions [7]. Design-based research (DBR) has been shown to be an effective methodology in the learning sciences for creating curricula, tools, and learning experiences that are deeply rooted in context and learning theory [8-10]. This approach involves teachers as 'design partners', allowing for the curriculum to be iteratively refined through short cycles based on pilot testing and real-world classroom feedback [9]. The involvement of teachers in this way not only enhances the practicality and relevance of educational innovations but also serves as a powerful form of professional development, bridging the gap between theoretical constructs and classroom realities [11, 12]. This partnership ensures that the resulting curriculum is ‘authentic’ i.e. theoretically sound and effectively tailored to meet the specific needs of students [13].

Even though design-based research has the potential of bridging theory and practice, research in the area is still emerging [10]. DBR studies often take place in one school or a few classrooms [10]. This study explores the evolution of a pre-college engineering curriculum, highlighting how it has been shaped through evaluation data collected from 47 high schools and 103 teachers over a period of three years from 2022 to 2024. The purpose is twofold: 1) to delineate the curriculum development process of the program, detailing its evolution from version 1.0 to 5.0, and 2) to share comprehensive evaluation data that reflects the reception of the curriculum across the last three iterations. By providing an in-depth look at both the progressive refinement of the curriculum and the empirical outcomes associated with each version, this paper provides valuable insights to enhance ongoing pre-college engineering education efforts.

Methods

Program Context

Large-scale pre-engineering programs tend to appeal to students who may already be planning to study engineering in college. These programs serve a purpose in helping engineering students prepare for college. However, these programs often fail to appeal to students who lack a fundamental understanding and appreciation of engineering adding to the continued challenges of increasing participation in engineering [14]. The National Science Foundation-funded a pre-college engineering program with the goal of democratizing and demystifying engineering [15]. The goal was to introduce engineering to all students, not just to those who planned to study engineering. Further, the goal was to show what engineering is and how engineering problem solving affects every-day life, and to provide all students with opportunities to discover and explore an engineering mindset and the “why” of engineering, not necessarily to create more engineering majors by convincing students to pursue engineering [16, 17].

The program uses a project-based learning pedagogy that engages students in engineering design with projects that progress in complexity from teacher-provided challenges to student-driven initiatives. High schools are paired with local partners who offer project ideas and expertise, enabling students to consult stakeholders and community experts while developing their projects. Students have the opportunity to follow an engineering design process multiple times during the year to design solutions to problems and develop design thinking, creativity, innovation, and collaboration skills.

Procedures - Curriculum Development and Evolution

The curriculum was initially framed in 2018 during a series of workshops engaging experts in K-12 engineering. The curriculum was based largely on the First-Year Engineering Classification Scheme [18], framed by El Sawi’s curricular development framework [19]. Workshop participants developed course outcomes and grouped these into four categories or threads woven throughout the curriculum. The course was originally broken into eight units, and each unit in turn is broken into a series of lessons with associated activities. Units 1 and 2 introduce the engineering mindset, engineering identity, and engineering as a noun and a verb. The Engineering Design Process is introduced here as well. In Units 3 and 4, students actively engage in problem identification and developing a solution to that problem using the Engineering Design Process, typically with teams designing solutions to a single problem local to their school [20]. Units 5 and 6 (as a group) and Unit 7 see students designing solutions to progressively more complex problems for a global issue and an issue personally important to the student. Unit 8 involves reporting out and communicating the solution. The pilot version of the course was offered during the 2019-2020 academic year, disrupted by the COVID-19 pandemic [21].

Each year, the curriculum developers and evaluators sought formative feedback from teachers and students for curricular improvements. From the pilot year of the original course, teachers found the entire curriculum to be daunting and had difficulty completing all eight units in one academic year. The course has been now broken into a two-course sequence, one for making and the other for design.

Procedures - Teacher Materials and Teacher Guide

The curriculum was shared with the pilot cohort of teachers (n=9) in the 2019-2020 academic year. The initial curriculum (which came to be known as version 1.0) was structured as a main Unit page with a series of lessons within each unit. These were shared as Google documents among the curriculum development team and the cohort of teachers. Teachers were encouraged to add comments directly to the documents. The main issue in the pilot year was the discovery that progressing through engineering designs took more time than anticipated, and teachers would likely not be able to accomplish each of the eight Units. Unfortunately, the COVID-19 pandemic severely disrupted the pilot year and vastly different policies were instituted by different school districts [22]. Given the small number of teachers, the curriculum team was able to work with teachers individually to transition to online / remote instruction [21].

The program teamed with *Teachengineering.org* after the pilot year. This gave the curriculum team a platform to develop and publish content and gave teachers a portal through which to access content and supplemental material. Modifications to the curriculum, now in version 2.0, were implemented to fit the existing structure of *Teachengineering*. The main change was to pull all activities from lessons, creating separate lessons with embedded activities. *Teachengineering* also had a mechanism to collect feedback - to “suggest an edit” which gave teachers a formal means to suggest changes or ask questions. As the teaching team grew (n=39), a community of practice was formed among existing and new teachers [23, 24].

Year 3 saw version 3.0 of the curriculum. The curriculum underwent an extensive and exhaustive review by the evaluation team, who had expertise in K-12 curriculum development. This resulted in changes throughout the curriculum. Most changes involved adding significant scaffolding, focusing on additional explanations of concepts or clarification, but in some cases, lessons were significantly expanded upon or rearranged, and new activities were added. This was especially helpful since many, if not most, of the teachers had no engineering experience and very limited exposure to engineering prior to teaching the course [25, 26]. A teacher-created repository of examples and resources was shared, allowing the teacher community to see examples of teacher and student work. Further, it became clear that it was very difficult to build all eight units into the academic year, so restructuring showed different paths through the curriculum, allowing a choice of a more structured or less structured engineering design project in the second semester.

Version 4.0 (generally in the 2022-2023 academic year) saw another round of evaluation with extensive formative feedback, focusing on areas where a need for scaffolding was perceived. The curriculum team worked with teachers to develop teacher-facing resources including slides for every lesson and activity. The 2024-2025 academic year, version 5.0, saw a large change, separating the eight units in half to create a two-course sequence separating making and design. This would ensure students would cover all of the content in the original course and receive a structure more suited to many states' academic standards [15]. The curriculum also had CAD-specific lessons added, most with accompanying videos, to introduce CAD, yet remain CAD-agnostic, not requiring a specific CAD program or requiring CAD at all [26].

Through each iteration, teacher feedback was collected and incorporated. Teachers were regularly encouraged to submit suggestions for improvements and corrections through the *Teachengineering* portal. The curriculum team has been active throughout, updating lessons and activities in response to teacher feedback. It should be noted that while this paper presents an overview of the curriculum development and evolution process spanning the past five years, the next few sections describe the evaluation results from v3.0 to v5.0 and emphasize the latest teacher feedback from the Academic Year 2023-24, offering the most current insights into the evolving impact of the curriculum.

Teacher Participants

Participants were a subset of high school teachers who participated in the program during 2021-22, 2022-23 or 2023-24 academic year. Over the three years during which data was collected, the teachers taught in 47 high schools in the 18 states and territories of the nation. The 47 high schools included public (*n*=31), charter (*n*=7), private (*n*=7), and alternative (*n*=2) schools in the states and territories of Arizona, California, Florida, Hawaii, Indiana, Kentucky, Maryland, Massachusetts, New Hampshire, New Mexico, New York, North Carolina, Pennsylvania, Rhode Island, Tennessee, Virgin Islands, Virginia, and Washington. Some schools had multiple teachers teaching the course in different sections. We acknowledge that the number of teachers who responded to surveys is less than those who participated in the program, which is reflective of the voluntary nature of research participation. Teachers were also not required to self-report any identifying information on our surveys in order to gather honest feedback on the curriculum. In AY 2021-22, 50 teachers participated in the program and 33 responded to the curriculum evaluation surveys. In 2022-23, 48 teachers participated in the program and 40 responded to the surveys. In 2023-24, a total of 57 teachers participated and 30 responded to the surveys.

Procedures - Data Collection and Evaluation Analysis

At the end of each school year, all teachers were requested to complete surveys about their engineering teaching self-efficacy, as well as their impressions, opinions, and experiences with the curriculum. The survey instrument was developed by the program's research and evaluation team members with expertise in engineering education research and pre-college engineering curriculum design. The measures asked teachers to rate the quality of the various aspects of the curriculum (e.g., "Rate the quality of the Teacher guide."), teacher materials, and outcomes including student engagement and student attainment of learning outcomes using a scale of 1 to 5 where 1=poor and 5=excellent. Additionally, for every Likert scale question, teachers were asked to explain their rating. The responses were analyzed for descriptive statistics.

Results

This section details comprehensive analysis of teacher feedback collected over three years organized under four categories: 1) curriculum; 2) materials; 3) teacher guide; and 4) perceived impact on students. As mentioned earlier, the curriculum, the materials and the teacher guide have been iterated upon over the years to accommodate teacher feedback and suggestions. Every new academic year, teachers had access to an improved version of the curriculum, materials and guide as compared to the prior year. As previously noted, the results focus on the latest teacher feedback from 2023-24, offering the most current insights.

Curriculum

Fig. 1 shows curriculum rating by the teachers. With the v5.0 in 2024 the largest percentage of teachers rated the curriculum as "very good" (43.3% in 2024, 31.7% in 2023, and 38.2% in 2022). That same year the percentage of teachers who rated the curriculum "excellent" dropped slightly but both 2024 and 2023 were significantly higher than 2022's rating (33.3% in 2024 vs. 34.1% in 2023 vs. 20.6% in 2022). While the percentage rating for "fair" remained fairly stagnant (10.0% in 2024, 9.8% in 2023, and 11.8% in 2022), the rating for "good" decreased significantly from 29.4% in 2022 to 24.4% in 2023 and finally to 10.0% in 2024.

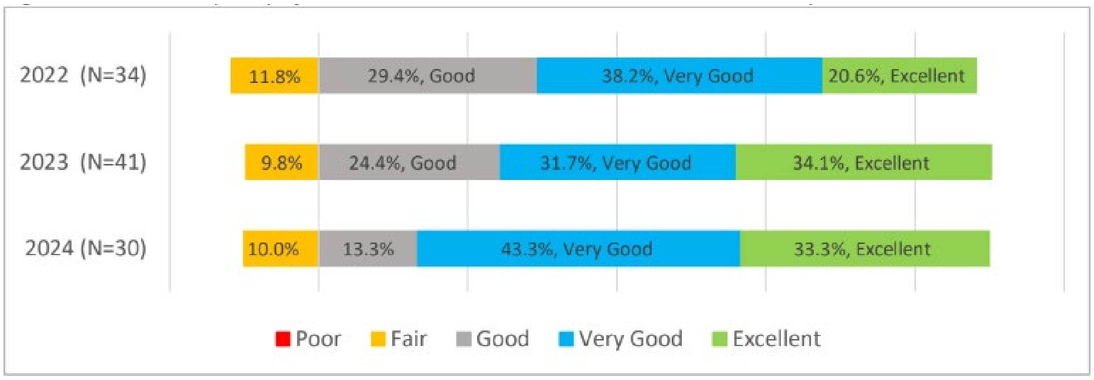

Fig. 1: Rating the quality of the curriculum lessons and activities to implement with students

The ten teachers who rated the curriculum as "excellent" in 2024 cited the quality and adaptability of activities, as well as scaffolding that builds over time. In the words of teachers, "there are a lot of great activities for students to engage in that will help them understand more about engineering," and "lots of good lessons that are quick and pointed to build a good scaffolding for later projects." The teachers that rated the curriculum as "good" suggested that while Units 3 and 4 were meaningful, Units 1 and 2 were harder to engage the students in engineering. Only three teachers rated the curriculum as "Fair" in 2024, and none rated it "Poor."

Materials

Various materials are provided by the program team to the teachers including worksheets, online forms, and other materials needed for constructing prototypes. Teachers were asked to rate the quality of these materials provided for student use (Fig.2). From 2022 to 2024, the percentage of teachers who rated the materials "excellent" increased and decreased by very small margins (33.3% in 2022 to 30.0% in 2023, to 33.3% in 2024). There was a substantial increase in the percentage rating the materials "good", from 18.8% in 2022 to 27.5% in 2023, and a drastic decrease in the same rating from 2023 to 2024 (27.5% to 20.0%).

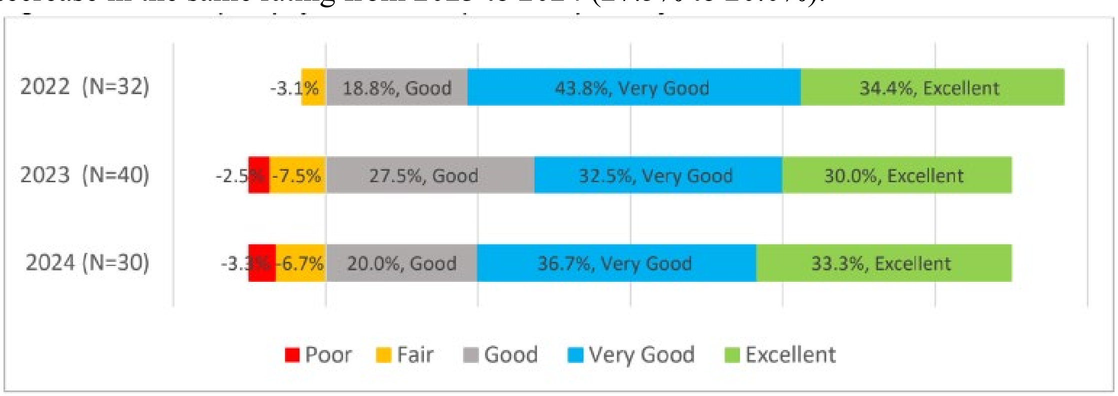

Fig. 2: Rating the quality of the materials provided to teachers for student use

Feedback on the materials was generally positive, highlighting the accessibility and practicality of both physical and digital resources. Teachers appreciated the support for purchasing and obtaining physical materials, noting their scalability and the use of easily sourced everyday objects. Nonphysical materials were praised for their rigor and well-organized structure. Out of the teachers surveyed, ten rated the material quality as "Excellent," appreciating both tangible and online resources. Eleven teachers gave a "Very Good" rating, with comments pointing to quick delivery and engaging content that excites learners. The six teachers who rated the materials as "Good" mentioned that while the materials are student-friendly, they require some adaptation to better fit classroom needs. Criticisms arose from two teachers who gave a "Fair" rating, specifically concerning the insufficient budget for physical materials, which they felt hindered the ability to effectively teach multiple courses. One teacher's "Poor" rating suggested adding more student-facing videos to enhance the learning experience.

Teacher's Guide

As explained earlier, the Teacher's Guide, hosted by *teachengineering.com*, contains lesson plans, student learning objectives, slide decks, videos, and student support materials. Compared to prior years, a larger percentage of teachers (Fig. 3) rated the teacher's guide as "excellent" (30% in 2024, 25% in 2023, and 15% in 2022). The percentage rating it "fair" or "poor" also increased, though not as much (10% vs. 7.5% and 9.1% respectively).

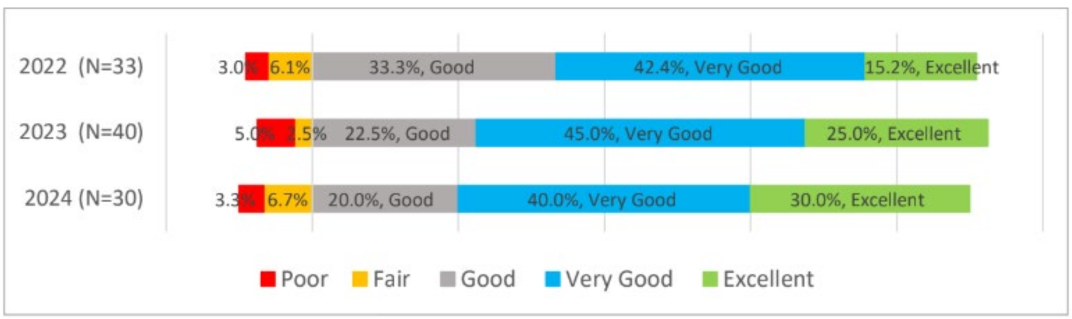

Fig. 3: Rating the quality of the Teacher's Guide

Comments and ratings suggest that there is room for improvement in the layout, website implementation, and timing. For example, those who rated the teacher guide as "excellent" highlighted its well-organized lessons and clear, explicit guidance. Another 42.4% of teachers rated the guide as "very good," praising its clear objectives, well-articulated plans with material lists, and simple, impactful videos and activities. About 33.3% considered the guide "good," appreciating its structured guidance on student learning needs and its accessibility.

Some teachers suggested improvements, noting that the layout of activities could be confusing and overly segmented, which complicated the learning process and required excessive navigation. Less than 10% of teachers rated the guide as "fair" or "poor," with criticisms focusing on the need for regular updates to keep the content current and critiques about the guide being repetitive and not concise enough.

Perceived Impact on Students

Teachers were also requested to rate their students' engagement in the course. In 2024, percentages rose on both extremes (Fig. 4). The percentage of "strongly agree" rose from 45.2% in 2023 to 50.0% in 2024 while a 3.3% rating appeared for "strongly disagree". This is correlated with a decrease in percentages for the "unsure" rating from 9.5% in 2023 to 3.3% in 2024.

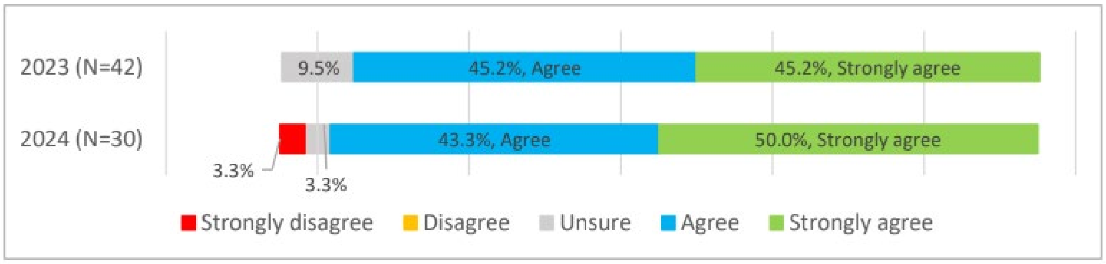

Fig. 4: Rating the engagement of students

The ratings below focused on whether teachers felt that their students had gained new knowledge through the course (Fig. 5). The 2.4% for "unsure" in 2023 disappeared in the results for 2024. Instead, the percentages for "agree" decreased and "strongly agree" increased. Regarding the former rating, the percentages fell from 38.1% in 2023 to 30.0% in 2024. The latter rating faced an increase from 59.5% to 70.0%.

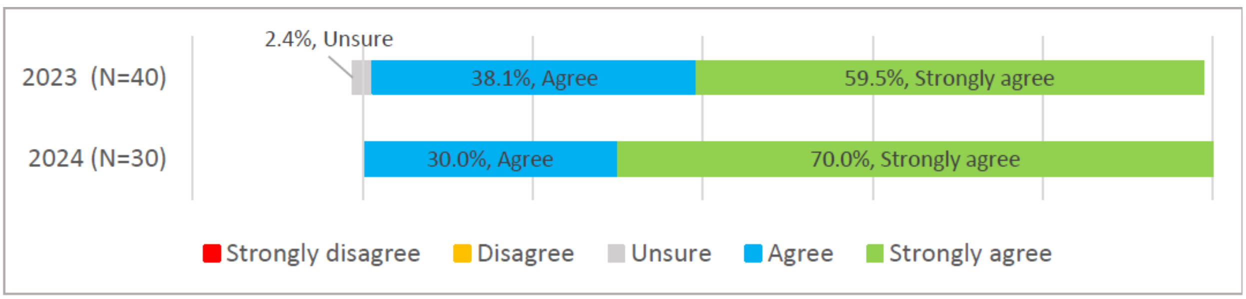

Fig. 5: Rating "students had gained new knowledge" throughout the course

These results indicate that teachers had good experience teaching the curriculum and observed that it was well-received by students.

Discussion

The discussion of our findings centers on evaluating the alignment between the goals and objectives of the program curriculum and the outcomes as evidenced by teacher feedback. The primary aim of our pre-college engineering education program initiated in 2018, was to demystify engineering concepts for high school students and to provide a welcoming educational experience that encourages all students to explore engineering [15, 16]. This was to be achieved through a carefully designed curriculum supported by comprehensive teacher professional development and a robust learning community [16, 24]. Evaluation results indicate that these objectives are being met with considerable success. Feedback from teachers has indicated that they feel well-supported and well-equipped to teach the curriculum. Teachers also reported a high degree of satisfaction with the curriculum materials, including lesson plans, activities, and student-facing resources. This positive response underscores the program's effectiveness in providing teachers with the necessary tools and confidence to deliver engineering education [5, 24]. Moreover, the positive reception of the curriculum by students, as observed by the teachers, reflects the curriculum's relevance and appeal to the student body. This suggests that the curriculum does not merely educate but engages students, an outcome that resonates deeply with the program's overarching educational goals to demystify and bring foundational engineering knowledge to all students.

In considering the authenticity framework, which advocates for the "thick authenticity" [13] of genuine and practical learning experiences that (1) present students with real-world engineering challenges; (2) encourage students to pursue projects of personal interest to them; (3) engage students in authentic disciplinary practices; and (4) assess students using a portfolio process authentic to real-world engineering reporting; our findings suggest that the curriculum's design and iterative development process are well-aligned with these principles. The ongoing adaptation of the curriculum based on regular and systematic feedback from teachers has ensured that the program remains responsive to the needs of both educators and students, thereby maintaining its relevance and effectiveness [9, 11, 12].

We acknowledge that external factors such as changes in educational standards or shifts in school resources and priorities could influence the effectiveness and reception of the curriculum. The study relies on self-report surveys which can introduce biases. Given the nature of the curriculum development process, the evaluative feedback focused on specific aspects of the curriculum such as usability of materials and guides. Our future plans include analyzing student surveys to examine the curriculum's impact on student engagement and learning outcomes.

Overall, the results from the latest teacher feedback reflect positively on the program's goals and development process. The curriculum's ability to adapt and evolve over time, informed by direct insights from those on the front lines of education, highlights a dynamic and responsive educational model that effectively prepares students for future pursuits in engineering and beyond. This dynamic DBR approach to curriculum development not only supports the authenticity of the learning experiences [7, 10] but also ensures that the curriculum remains at the forefront of educational innovation for all students [4, 11]. By emphasizing continuous improvement and adaptation based on direct stakeholder input, this work contributes to a deeper understanding of how educational innovations can be effectively tailored to meet educational needs and improve teaching outcomes.

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