2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #39271

Using Backwards Design to Redesign a First-Year Engineering Seminar to Serve a Diverse Student Population

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Using the CAP model to Equitably Redesign a First-Year Engineering Seminar

Introduction

The student body in higher education keeps changing, making it critical to pay attention to new generations' challenges toward achieving their academic goals [1]. Generation Z students are the core of the current student population at colleges and universities. They have traits to acknowledge and make the most of, for example, their "native digital" nature. Generation Z college students also view college as a way to lead a career with purpose; therefore more likely to be motivated by the change they can make in the world. They also have specific challenges which are important to consider, the primary example being the stresses and losses derived from learning within a pandemic [2]. Generation Z students are also the most diverse generation in modern American history. In honoring a commitment to support student success, it is important to consider these strengths and challenges. In addition, the weed-out culture of engineering should be replaced with a culture that supports the success of a wider diversity of students.

Some universities have identified that the proportion of students that find it necessary to work to pay for their college expenses is growing; these students are also recognized as having weak time management and organization skills [3]. Instructors and administrators are paying attention to the keen needs of the incoming generations of students. At a University at Buffalo, a recent policy change has made space for revamping a highly impactful first-year engineering course which will now incorporate a wider audience of students [19].

Under such an opportunity, and considering our students' characteristics, the course redesign took place using the Content, Assessment, and Pedagogy (CAP) model [4], which is based on backward design. This paper describes the first stage of redesigning a 3-credit first-year seminar for engineering students to provide equitable training for first-year engineering students joining the institution for years to come. We provide the rationale for the course's enduring outcomes and learning objectives and a report on the challenges of building them cooperatively within a diverse team of educators. Throughout the paper, we include the reflections of the redesign team framing their perceived challenges and the advocated shift of priorities for the course. In particular, those related to enhancing the sense of belonging for first-year students. Our report aims to illustrate a process that others can engage with within their own goals of enhancing equity within the first-year experience.

Backward Design and the CAP model

The backward design of curricular development starts with the basic idea of starting from the end, where we envision our students to be after the learning experience we are designing [4]. Its central premise is that once the educational purposes (i.e., the learning outcomes) of a learning experience are conscientiously selected, the rest of the elements of the experience (i.e., the pedagogical activities, and corresponding assessments) should be designed toward the achievement of those identified outcomes [5]. Therefore, the three main stages of backward design are: (1) identifying desired results, (2) determining acceptable evidence, and (3) planning learning experiences and instruction. The core elements of the first stage (identifying desired results) are leveraged by identifying the big ideas and essential questions that frame the ***enduring understandings*** that we expect our learners to achieve [5]. This goes hand in hand with identifying aspects of knowledge that can be located at other levels within our learners' priorities (i.e., important to know/good to be familiar with).

The concept of backwards design of learning experiences has been part of the literature for some time [5], and its general idea is not foreign to the practice of seasoned educators [6]. The backward design has also

been extensively used in the literature as a tool to address the issues of training of K-12 educators [7], K-12 education in general [8], and language learning [9], as well as multiple contexts in college education, such as nursing education [10], chemistry labs [11], and undergraduate research experiences [12]. Nevertheless, elements of backward design have adapted and evolved within specific contexts, offering updates to the model itself.

The Content, Assessment, and Pedagogy (CAP) framework, proposed by Streveler & Smith [13], harness backward design but was developed within engineering education. Therefore, it parallels the process of designing a learning experience to that of engineering design. Because of the need to consider non-cognitive outcomes, such as skills or attitudes, Streveler & Smith use the term ***Enduring Outcomes*** rather than enduring understandings. Figure 1 summarizes the structure of such curricular priorities identified by the backward design model, using the modified language proposed by Streveler & Smith [13].

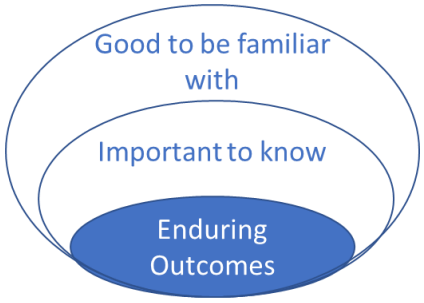

Figure 1. Levels of course content adapted from Wiggins & McThige [4] based on the CAP model [13].

The core element of the CAP model is the alignment between the content, assessment, and pedagogy elements, having the enduring outcomes as the main driver for the design [13]. In addition, the Streveler & Smith CAP framework, which has been taught for more than a decade at Purdue University [13], has infused the execution of backward design with tools that facilitate its different stages. For the first stage, (1) Content, the use of concept maps is suggested as a tool to explore the relationships between the concepts, big ideas, and essential questions under consideration. For an example, see [14].

Most engineering education scholars that have engaged with the CAP framework for course design, and its backward design essence, have done so under the previously mentioned course at Purdue University [15]. During a course-planning process, it may be helpful to devote sufficient time to design or redesign thoroughly throughout a semester. However, redesigning a course can have multiple restrictions in real contexts, especially time-related ones. While the endeavor described in this paper aimed for a complete redesign of an engineering seminar in first-year engineering through engagement in all the stages of the CAP model, due to time restrictions, the assessment and pedagogy steps were not revamped during the considered period. Therefore, this paper only includes the Content element of the exercise as a backwards design experience using the CAP vision.

The Context

The first-year seminar is part of the core curriculum at University at Buffalo [16]. All of the first-year seminars provide an introduction to students' college education and are designed with the idea to develop critical skills in order to succeed in future coursework (e.g. study skills, time management skills, etc.), as well as to get an entry level introduction to their areas of study [16]. Therefore, the first-year engineering seminar, *EAS 199: Engineering Principles*, aims to provide students with an introduction to engineering thinking and engineering design in addition to the tools to succeed in their new college environment. In the late 2000s, providing students just exploring the possibility of pursuing an engineering degree was

deemed appropriate with an adjusted version of the first-year engineering seminar. This version was comparable but differed in depth and rigor. The two versions of the seminar were for (a) **accepted engineering** and (b) **intended engineering** students.

The intended group made up approximately 35%-40% of the first-year engineering cohort. This percentage of the first-year cohort remained consistent since 2016; however, it was a more diverse group in terms of race/ethnicity and first-generation status than that of the accepted students consisting of over 30% underrepresented populations as compared to 17% in the accepted cohort. Although not formally studied, there were concerns expressed by some students that the delineation of accepted vs. intended majors, and seminars, was contributing to a negative association between the intended/accepted divide being tied to their chances for success in engineering. Our statistics also showed that the intended group had a higher proportion of students with marginalized identities, such as students of color and first-generation students.

In summary, what was planned to expand the participation of those that were considering engineering only as an option seemed to end up being perceived as an unfair differentiation determined significantly by inequities in the educational pipeline.

To advance the school's equity goals [17], a policy change in 2022 was made to integrate the two groups of students in the same cohort of first-year engineering students. With the intended engineering majors now combined with the accepted cohort, the challenge was to develop a distinct type of engineering seminar that would consider the merged student population. There were strengths and weaknesses from both previous versions of the course, which had to be considered to develop a unified revamped version that would best serve both groups of students equitably. In Spring 2022, a committee established by the Associate Dean for Undergraduate Education began working towards the first edition of this new course, launched in Fall 2022.

The Team

The redesign committee included diverse faculty in terms of their experiences, including five traditional tenure-track faculty, two full-time teaching faculty, and one staff-level instructor. Many of these faculty were previously involved in teaching the intended and accepted versions of the seminar and therefore brought such previous knowledge to the redesign task. Additionally, faculty who were historically involved with the seminar and faculty that interact heavily with students through experiential learning were also involved. The committee was led by the Associate Dean for Undergraduate Education at the Institution and was facilitated by one of the tenure-track faculty members, who is an engineering education expert. The range of teaching experience among the team was from four to more than 30 years. In addition, the team was also diverse in terms of individual backgrounds, including different engineering majors, as well as representation of women faculty, faculty of color, and faculty with first-generation status.

All faculty were familiar to some extent with backward design, either formally or informally. One faculty in the team introduced others to the nuances of the CAP model, and regular meetings were established starting in Spring 2022.

The Process

The team met every week for two months. In the first stage, a committee member facilitated other members with the nuances of the CAP model and backward design. As suggested by Streveler, Smith, and Pilotte [14] a concept map was created to determine the aspects of Content and their relationships. The priorities of the course were extensively discussed, including the team members' perceptions of the challenges of merging the "accepted" and "intended" groups. The graphic representation by the faculty member who was facilitating the CAP model of the Content helped prioritizing the creation of different enduring outcomes.

Once the enduring outcomes were set, the whole team brainstormed how to operationalize the vision of the enduring outcomes through learning objectives. The team engaged in a collective effort proposing different versions of the set of learning objectives, and after some iterations, the team achieved a collective agreement.

Even with the revamped enduring outcomes and learning objectives, due to time restrictions, there were limited changes that the team was able to revamp the assessments and pedagogies for the course. The first edition of the course under revision took place in Fall 2022, and the faculty intend to reflect and review the first course offering in terms of the alignment between the Content, assessment, and pedagogy prior to the Fall 2023 edition.

In Early Spring 2023, five of the faculty involved in the process wrote reflections around their experiences participating in the 2022 redesign of the Content for the purpose of this paper. Such reflections are offered by these faculty throughout the paper as a report on the collective beliefs, identified challenges, and the work ahead as the redesign keeps evolving.

The students

Understanding the learners is essential to a course design [7]. Characteristics of the current student population were considered throughout our discussions. When team members were asked; *in your opinion, what was the biggest challenge derived from the merging of "accepted" and "intended" students?* One of the involved faculty focused squarely in the characteristics of the current generation of students:

> I think that that the redefinition is across the board for first year students and not particular to the combination of the intended and accepted. Students today seem less resilient or just plain worn out…no fight left.

Other faculty were concerned about the ability to motivate students in both extremes of the new continuum:

> My biggest concern is that students who would have been "intended" might become more disheartened by interacting with and observing students who would have been "accepted." Put differently, I would fear that it would show them first-hand that they were not at the same level of ability as others in their class. At the same time, I would guess that being admitted as "intended" instead of accepted might have had similar effects. I guess for me it comes down to motivation: how can both the higher ability and the lower ability students be motivated to learn in the mixed class.

Nevertheless, others came to the task recognizing potential differences, but were more hopeful on a collective capacity to implement evidence-based student-centered practices that could rightfully serve the student continuum:

> Different academic preparation of students in terms of math/science courses could be considered to be a challenge. However, in my perspective, if an approach which includes constructivism, differentiation, and true student-centered learning is used, it should not matter if students would have previously been considered to be "accepted" and "intended" students.

These comments illustrate the spread of perceptions existing across the team about the problem at hand, as well as the capabilities of the team to produce a successful redesign.

Concept mapping

Figure 2 presents the concept map generated by the committee to represent the course content priorities. The first version of this concept map was generated by the facilitator and the rest of the members supported edits and changes through live discussions. The elements derived from the green ellipse correspond to items required from all first-year seminars at the institution, including the development of general skills for academic success. The pink ellipse relates to the high-level engineering knowledge that we expect first year students to acquire, in particular, a conceptualization of engineering design through evidence-based decision making, and the development of professional skills, which do not differ significantly from what has been documented extensively in the literature, such as professional skills [18], [19].

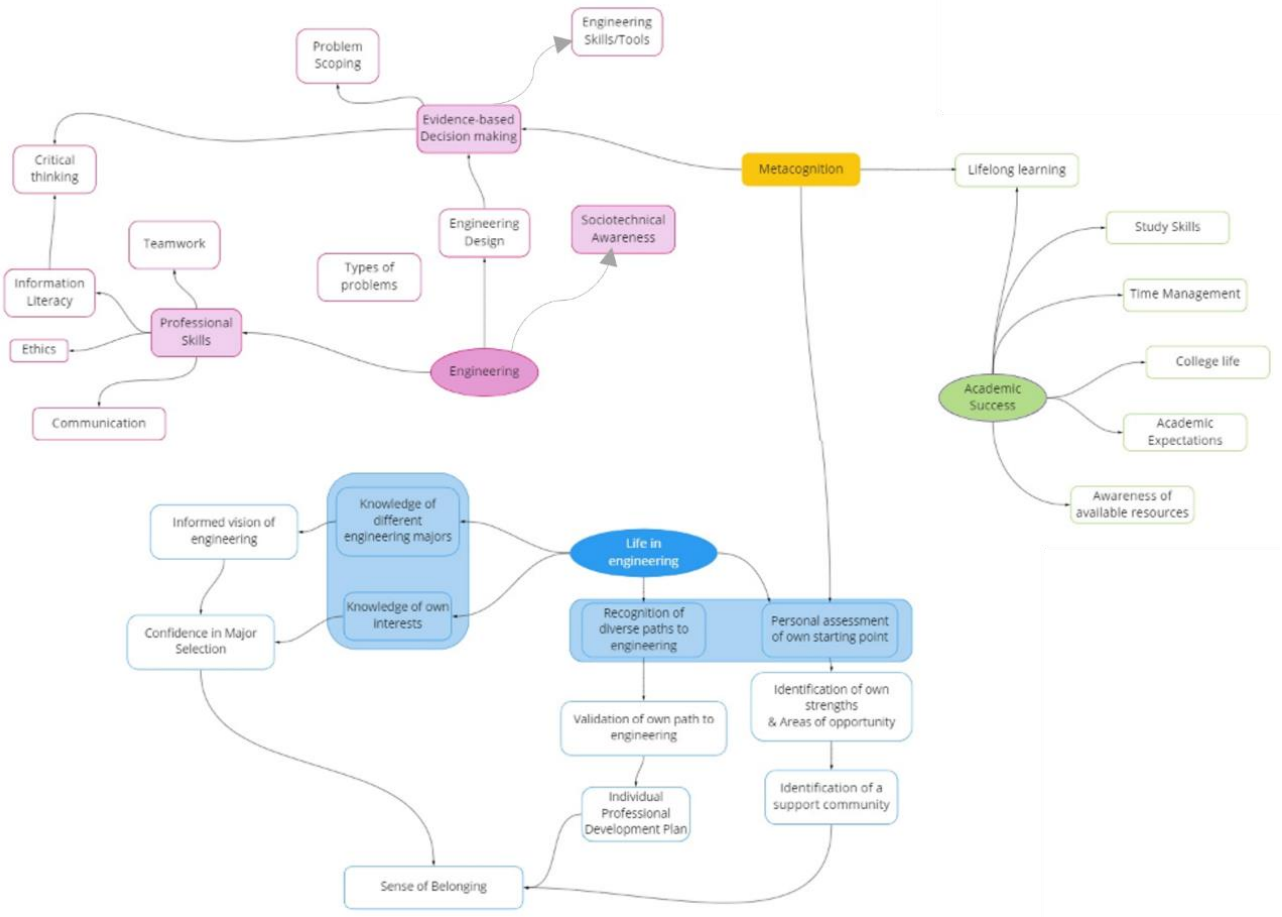

Figure 2. Concept map of considered big ideas and concepts driving the course redesign.

Because the documented demographic differences between the intended and accepted populations (i.e., a higher proportion of first-generation students and students of color in the intended group), we paid particular attention to literature on the barriers to marginalized groups' success. Extensive literature has identified sense of belonging as a critical factor in the retention of marginalized groups, such as women and ethnic minorities [20]–[23]. Therefore, the team looked for opportunities to equip those that would have been part of the intended group to develop a sense of belonging in engineering that would support their skills development and potentially enhance their retention. Therefore, the blue ellipse of life in engineering aimed to capture our collective intention to support students' sense of belonging and enhance retention into engineering degrees.

The two key elements of this process were: (1) providing students with sufficient knowledge about the different engineering majors to better inform them of an intersection of their engineering major decision and their interests, and (2) offering students with a more realistic purview of engineering education pathways. Part (1) was traditionally included as part of the informal course objectives before; however, it was not made within the context of the passion-driven decision-making that is documented as influencing Gen Z's choice of careers. The team envisioned providing opportunities for students to engage in reflection about the alignment of different engineering majors and the students' true interests and passions. Part (2) resulted from the lobbying of committee members that held one or multiple marginalized identities and or non-traditional paths, the goal was to emphasize that obtaining an engineering degree did not have to be a linear process that lasted exactly four years, decrease the focus on competition and enhance students' sense of belonging. It was deemed that such considerations would benefit the growing numbers of students with commitments outside of their academic duties (e.g., work, family) [3]. Some team members were concerned that transmitting prevailing meritocratic narratives that pose students with disadvantaged profiles as "failing" or "behind" would do a disservice to the increasing number of students that realistically cannot commit to direct 4-year paths. By supporting students' ability to identify a realistic personalized path toward their degree, it was considered that this could make space in the design for a more diverse student body.

Finally, since we expect students to become conscientious evidence-based decision-makers, lifelong learners, and generate a personal assessment of their own starting points, we identified that metacognition skills reflected on a thread that captured the three previously discussed areas. Therefore, it is denoted as a big connector in the center of the concept map (yellow). The development of student metacognition skills also aligns with the team's intention to support students' agency by enhancing their ability to self-regulate, and self-monitor [24]. Metacognition, the knowledge and regulation of one's own thinking processes, has been documented to be critically important to student learning [25]. Recent research has demonstrated that intentional infusion of opportunities for students to reflect on their own learning and develop metacognition skills can improve engineering-specific academic outcomes [26]. There are transferable tools to teach metacognition abilities to engineering students [27] that have proved effective in supporting students' gains [23]. Therefore, opportunities exist to engage in small-effort interventions that will significantly impact students' gains.

Enduring Outcomes and Learning Objectives

The finalized enduring outcomes and learning objectives that guided the first iteration of the seminar's new version are presented in Table 1. Learning objectives 1 and 2 were purely related to engineering skills but also attended to the field's equity and inclusion pressing needs by acknowledging the need to work with diverse teams and communicate with diverse audiences. Learning objectives 3-6 relate to academic success and engineering major selection as the team identified different challenges derived from the increasing diversity of our students.

Table 1. Enduring outcomes and learning objectives derived from backwards design collaboration for EAS 199.

Enduring Outcome		Learning Objective
1	Engineers work ethically and collaboratively in diverse teams to solve different types of ill-defined problems using evidence-based decision making	Create solutions to complex real-world problems using evidence-based decision making while working in inclusive and effective teams
2	Engineers communicate effectively with technical and non-technical audiences from diverse backgrounds	Communicate effectively with technical and non-technical audiences from diverse backgrounds
3	Successful students use a variety of strategies to effectively manage their time, study, and recognize of opportunities of continuous learning	Create an individual academic success plan as a UB student
4	All the different engineering fields bring essential solutions to pressing needs of diverse populations in society and complement each other	Generate an informed decision of the engineering area to pursue
5	Engineers have the agency to choose the type of problems they want to solve	Identify the motivation to pursue an engineering degree
6	Engineering is a feasible professional pathway with multiple starting points	Create an individual and realistic professional development plan to pursue an engineering degree

When prompting the team members about *which Enduring Outcomes (EOs) and Learning Objectives (LOs) did you feel the most involved in developing and why?* they offered summaries, including the experience itself, such as the following:

> I feel that the process of developing the Enduring Outcomes was a team effort. Group discussions of skills which can help engineers succeed guided the development of the outcomes. All committee members were provided with an opportunity to contribute thoughts on outcomes. Some committee members were tasked with categorizing the initial thoughts, and then a review and process of adjustment was completed as a team. I may have been more involved in developing EO-1.

In addition, some offered why particular EOs were closer to them. For example, one team member that has multiple marginalized identities described, *"I feel EO6 resonated the most with me because my path was nontraditional with lots of sticking points along the way."*

Similarly, another team member shared:

> I feel that I was most involved in developing EO1, EO5, and EO6. At least those are the ones I remember being most interested in and most discussing. I was most interested in those because I believe those are aspects of the engineering educational experience that either remain hidden to students (EO1) or are most important to evolving engineering education in ways to support a more diverse group of students (EO5, EO6). This latter issue seems particularly important in the context of our effort to remove labels and associated stigma that can be associated with those labels.

The first run

Armed with these revamped curricular priorities, the instructors for the course kept collaborating in restructuring course pedagogies, and their assessment. Fall 2022 was the first iteration of this innovation and it became evident that there is a long road to optimizing student experience based on the newly defined

priorities. Only a few innovations on the assessment and pedagogies were implemented for LO3, which involved supporting students' development of time management skills, metacognition skills using existing materials [27], and student reflection of career choice using existing materials provided by the institution's Career Design Center, and newly designed portfolios. There was no research-based measurement of the success of such activities nor of the achievement of students, but the team saw the potential for such inquiry as well as those related to the long-lasting effects of the gained time management skills in their academic success.

The Challenges

When prompted about the main challenges they found in the actual execution of backward design, some team members generally identified attitudes and time limitations. One team member reflected: *"I think the biggest challenge in the merged version was actually the instructional staff (Instructors and TA's) and the predisposition that was brought to the table."* Research has shown that different types of stakeholders can propel or decelerate change projects in academia [29]; it would be important to integrate what is known about change literature to overcome such challenges in the near future.

Time limitations were also identified. Significant time was shifted from the redesign process to address the logistical challenges of executing the course. Such considerations were necessary but should have been led by the redesign of the priorities rather than the reverse. In this team member's words:

> I think moving the conversations about how to revamp the course beyond logistical concerns was the biggest challenge. Of course, those logistics are important considerations […]. However, I think we missed an opportunity to really overhaul the class in important ways while retaining features of what has been found to work. I believe there is real potential to redefine some of the activities and to work toward experiences that push students to use some of the experiential learning resources.

Not surprisingly, the amount of time that the process took was certainly a challenge, in the words of another team member:

> I did find the process to be challenging in this course redesign […]. I would attribute this to a lack of time available for all committee members to devote to the process at the start. I also found it challenging to streamline the objectives for a course that could attempt to address too many objectives in one semester…

Based on these responses, it appears that the time necessary to generate a productive collaboration among such a diverse group of educators is a significant restriction that would need to be considered in moving forward with the assessment and pedagogy elements of the redesign.

The Gains

When presented with the prompt, *how do you think this experience helped you grow as educator or co-designer of educational experiences?* Team members referred to the complexity and intentionality of the experience, as well as the ability to rely on others for the reaffirmation of opinions and rely on experts outside of their own domain and those from engineering education.

One team member mentioned how the experience was the most complex process in which they have participated so far:

> I have previously worked with team-developing of core course components, but not this extensively. I feel that all courses are unique, and all new teams bring new perspectives. It was certainly the most complex process for developing core course priorities that I have ever been a part of.

Similarly, another member referenced the value of the intentionality of the exercise:

> This was not my first time being involved in the development of core course priorities. However, I do think it helped me grow as an educator in terms of being more intentional in mapping course priorities through enduring/learning outcomes and with support from a specific pedagogical design philosophy.

One team member reflected on feeling validated they felt in the team environment of this redesign as their ideas were synergistic with those of other members of the team:

> This was not the first time in a team environment developing a course, however my natural being is to hang back and not be front and center. So occasionally some of the thoughts I did have were not expressed or fell in line with what was already expressed, and I didn't articulate. From a growth perspective it reinforced the idea that my thoughts/contributions are relevant because other people had them and that I need to learn to consider more perspectives.

Finally, one of the most experienced educators in the team reflected on how interacting with engineering education experts and using new tools brought value to them:

> As an educator with deep domain knowledge of [specific] engineering being exposed to deep domain knowledge in engineering education provided me that greatest growth and insight. Having exposure to concept maps (fancy doodles) was new; as was at times having language for things that I had done in other classes; but the biggest take away for me personally was the collaboration with experts in engineering education.

Next steps and take aways.

In this paper we have reported on the first stage of course redesign using the CAP model and backward design, (1) identify desired results. The next stages of this redesign will involve a thorough redesign of the assessments methods and pedagogies used. Such redesigns are planned to begin in Spring 2023 with the next iteration of the course taking place in Fall 2023. Additional research-based documentation will be collected to evaluate the achievement of the redesigned goals.

While some of the course priorities remained aligned with the technical aspects of engineering, enduring outcomes related to academic success were explicitly added and given the same weight that the engineering outcomes. Because of the need to merge the previously labeled accepted and intended groups, the team also paid attention to supporting the development of students' sense of belonging through specific enduring outcomes that make space for non-traditional engineering education pathways. Metacognitive skills surfaced as essential to all dimensions of knowledge spanning all enduring outcomes.

Members of the team started at different points in terms of their understanding of the merged student population for this course. However, the process of collaboration in the development of the enduring outcomes provided all members to synergize on each others' ideas and find a common ground that would honor the needs of both groups of students without alienating either group. Faculty involved identified cross-field interactions, collaborative design of outcomes, and validation as some of the gains of this experience.

The team also reported on the realization that team-based course redesign is a time consuming process and a multitude of barriers exist to make it efficient in a regular institutional context within a research intensive institution. We look forward to formally collect data and contribute to further evidence through scholarship of teaching and learning. Generation Z students, the most diverse and inclusive group, seek real-world skills that prepare them for a career. The ongoing course redesign, although challenging preliminarily provides an equitable foundation for the students to gain real world skills that will help them see their fit in and obtain an engineering degree. The instructor team is committed to full implementation of CAP.

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