Students as the Teachers: Positioning Undergraduates as Experts, Role-Models, and Guides to create Diverse Learning Communities

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***Abstract*—We present a novel upper-division undergraduate engineering course that trains the trainers in active learning and inclusive pedagogy to "Lead by Design," i.e., teach a First Year Design class. Peer-led learning is commonly used to supplement course instruction and, increasingly, to support university makerspace programming in building communities of learning around these spaces. This practice has been shown to establish a more accessible and empathetic learning environment that benefits both the mentors and the learners. However, its usage falls short of formally positioning students as topical experts and leaders within a university's main curricular structure. As a result, the benefits of social learning are relegated to extracurricular or peripheral activities, inhibiting many learners from belonging to an engineering learning community of mixed-year peers.**

In this innovative practice, we position undergraduate students as teachers of a formal course to create a more welcoming and accessible learning environment for our first-year students, one that offers a more diverse representation of what engineering looks like. This study examines the quarter-long course, Lead By Design, where undergraduate student-teams develop, practice, and prepare to teach a First Year Design course around a skill-building topic that they propose. In this way, first year content is created for students by students; learners genuinely value the topics and the enthusiasm with which these topics are offered, which have included: 3D Design & Printing, Rocketry, Cybersecurity, Circuit Design and the EDA Toolchain, and Autonomous Vehicle Control, among others. Qualitative and quantitative data, along with external observations of the two-quarter program, show that learners are more willing to participate in and direct their learning within the low-risk and approachable learning environment created by student-teachers. These courses are beginning to organically cultivate mixed-year communities of practice as students form relationships that extend beyond the boundaries of the class, with many returning to enroll in Lead By Design so they may teach their own version of a First Year Design course.

***Index Terms*—engineering identity, peer instruction, active learning, community of practice, inclusive pedagogy, First Year programs**

I. Theoretical Framework & Context

A. Engineering Identity

Developing a professional identity has been shown to significantly affect persistence in STEM fields, both during an undergraduate's studies and in becoming a STEM professional after graduation. Literature surveying identity work and belonging among engineering students *in particular* identifies several critical factors that impact the development of an engineering identity: 1) the student's perceptions of what engineering is and what engineers do, 2) whether these constructs align not only with their *professional goals* but also their *personal values*, 3) their perceived self-efficacy or ability to do the engineering work, and 4) that engineering is inherently gendered as male [1] [2] [3].

Undergraduate students' identity negotiation is ongoing and informed by how they understand and relate to the engineering field at any given time. Thus, their definition of engineering, value affordances, and perception of their own skill can be altered through increased exposure and engineering practice [1] [2] [3] [4]. The affective nature of the factors described above, however, tells us that the intentionality behind these experiences matters. For example, the correlation between poor performance in introductory STEM courses and attrition among minoritized students shows that simply increasing exposure can be detrimental [5]. Students gain access to engineering practice through a variety of venues, both within the university curricular structure but often outside, such as experiential coursework, internships, makerspaces, extracurricular activities and clubs. Yet, this increased exposure to engineering may serve to change – or simply confirm – already existent perceptions of belonging which are based in socio-historical contexts [1] [2] [3] [4] [6].

As early practice is largely formative, it is critical to provide early experience to do engineering in a learning environment intentionally designed to:

- Expose students to *varied, real-world applications* of the field.
- Support interactions with *diverse professionals* and faculty that represent multi-faceted engineering roles.
- Make affirming connections with engineering peers who see the individual as part of an engineering community [1] [2] [3].

B. Peer-led Learning

Here, we focus on constructs that promote the emergence of peer-led learning communities. The benefits of social, collaborative, and cooperative learning environments are well established in engineering education research. Participants build technical knowledge and skill, improve their confidence and social competencies, and develop self-directed learning and critical thinking skills [7]. Peer-to-peer learning often takes place in active classrooms, through curricular peer tutoring programs, extracurricular peer mentorship (e.g., clubs), and increasingly, university makerspaces.

Peer tutoring programs are perhaps the most established, where students with higher-level competency mentor students newer to the subject in classroom learning. Generally, tutors are paid and receive formal training to support mentees through faculty-led activities. These programs have shown that peer tutors are often more empathetic and approachable than faculty instructors in addressing questions and difficulties, as they can better relate to their fellow students. Moreover, the tutors also benefit as learning through teaching furthers their own knowledge synthesis [7] [8]. These experiences promote a sense of community by connecting students to their peers to build vertical integration, but not necessarily belonging.

Another avenue for peer-to-peer learning happens in extracurricular spaces such as engineering clubs or hackathons, where mixed year students work together toward a project goal. In these settings, learning is peer-led rather than faculty-led and there may not be any associated curriculum. More experienced students organically become mentors for the less experienced participants; thus, this model incorporates many of the benefits of the tutoring model but without the formal training and positioning in teaching. Engineering clubs can be viewed as authentic communities of practice that form around a common interest, one that legitimizes peripheral participation [7] [9]. However, clubs also suffer from high rates of attrition, partly due to their extracurricular setting but also from pressures from both within and outside of the group.

Similarly, university makerspaces have emerged as sites for collaborative, peer-to-peer learning through making that potentially build topical communities of interest or communities of practice [7] [10] [11] [12]. In these settings, students often hold prominent positions (paid or unpaid) within the administrative hierarchy as staff, equipment trainers, and other leadership roles to affect the design, programming, and activities for student engagement within the makerspace. Their influence may range from providing input on equipment purchases to fully designing and implementing learning artifacts, such as workshops or training modules. Makerspaces that engage students as staff therefore incorporate the accessibility and approachability of peer-led learning into a space that promotes taking risks and learning from failure, enhancing the creative efficacy of learners [8] [13].

Notably, these spaces for peer-led learning are predominantly extracurricular and therefore support informal networks of mixed year students as communities of practice. Pedagogy within these spaces is not well-studied; but research does show that these communities are not equally accessible to all students and that marginalizing practices prevalent in engineering education still persist [10] [8] [11]. Positioning peer-led learning outside of the curriculum automatically limits participation to those with the time and inclination to not only opt-in, but also learn the rules and norms of the established community. While joining a community of practice is a choice, it should be one that is based primarily on mutual interests. Underserved students who do not have this time, do not feel as if they have the skill, or traditionally do not feel welcome still do not opt-in. Student-leadership in these spaces, generally trained in the safe operation of its equipment, is seldom made familiar with inclusive language and equitable practices that could broaden the participation of minoritized learners. University makerspace administrators are now recognizing that student staff must themselves be trained to facilitate welcoming and experiential onboarding for new participants to effectively connect them to the larger community of practice [7] [8]. One author posits “student staff as the innovation in engineering makerspaces,” as they have the potential to create truly inclusive communities of practice or perpetuate exclusive norms in engineering spaces [8].

C. University-Specific Context

Our School of Engineering is piloting a program that leverages the documented benefits of peer-led teaching within our engineering curriculum by formally recognizing our students as experts and teachers of our First Year Design series. First Year Design is part of a multidisciplinary initiative to introduce situated opportunities for engineering practice earlier through experiential skill-building. We recognize that tackling challenges to equity is more than simply providing further engineering experience; it requires purposeful efforts to create approachable, inclusive, and collaborative spaces for the identity work of our first-year students. Lead By Design, our ‘train-the-trainers’ course, aims to build student-teachers’ capacity to challenge marginalizing norms prevalent in engineering education. It affords undergraduates some measure of control over what is taught and, perhaps more importantly, how it is taught.

In this study, we examine the intentional curriculum of Lead By Design, a course that experientially prepares student-teachers to design a learning environment that emphasizes engagement of all learners. We hypothesize that positioning students as teachers in a credit-bearing course tangibly changes the learning environment to create sustaining communities of practice that exist beyond the context of the course, by:

- Placing undergraduate students at the top of the hierarchy - they are the experts and, as such, are established as engineers.
- Creating a more approachable learning environment centered around communal interests in an engineering topic.
- Granting unit and General Education credit for participation in making and engineering practice.

- Building confidence in an engineering toolkit of professional and technical skills to enhance self-efficacy in project-work.

As First Year Design transitions from the pilot phase towards integration with departmental curricula, we aim to use this work to elucidate practices and barriers for Lead By Design in achieving its objectives: 1) to cultivate more inclusive learning environments through 2) the development of a diverse set of mentors skilled in equitable leadership. Data collected during this pilot phase are analyzed to capture emergent themes and perspectives from learners and student-teachers. These findings are presented for discussion, highlighting key practices within Lead by Design for building a more inclusive program.

II. Synopsis of the Lead By Design Program Cycle

The Lead By Design (LBD)/ First Year Design (FYD) Program is designed to structurally support the ongoing identity work of developing engineers as they navigate the university ecosystem. First Year Design is a series of active, skills-based classes held in the makerspace classroom. With limited enrollment numbers and no prerequisite knowledge, these courses attract students across disciplines. They are designed for those interested in becoming proficient in a particular topic area so they can apply their new skills toward their own projects and goals. Lead By Design, a 5-unit (15 workhours/week) course, is the prerequisite for upper-division undergraduate students to teach a 3-unit First Year Design course to lower-division learners (9 workhours/week).

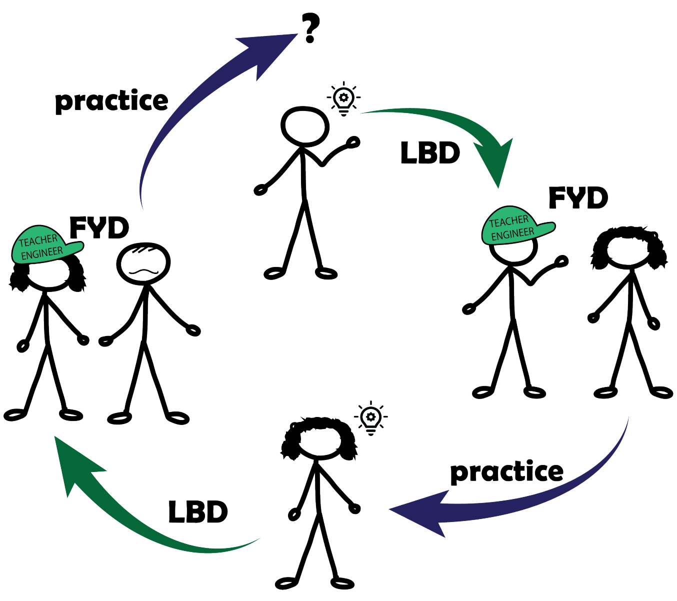

Fig. 1. Representation of the Lead By Design programmatic cycle, depicting the flow from course development in LBD through the transfer of knowledge and skills in FYD to bolster student leadership.

First Year Design provides early-stage students with experience doing engineering in a more casual, welcoming, and low-risk environment. The mentorship, support, and feedback given by student-teachers is more approachable than that of typical faculty, as fellow students are more empathetic to the learners' situations. Moreover, its high-structure framing makes formative engineering experiences, typically found later in an engineering program, accessible to first-year learners. Learners have various opportunities to apply and showcase content knowledge, learn (and recover) from failure, demonstrate skills through equipment check-offs, and traverse the engineering design cycle through smaller projects that lead to a culminating team-based project experience. The specific skill-building topics offered in First Year Design are proposed by undergraduate teaching teams and developed in Lead By Design; thus, topics offered vary depending on the intentions, backgrounds, and availability of the student-leads. Since the program's pilot in the 2020-2021 academic year, student-teams developed 11 unique courses, many of which have been taught over multiple iterations:

TABLE I
Titles of the various First Year Design courses that have been developed and taught by undergraduate student teaching teams. Many of these topics have been taught multiple times or iterated upon to emphasize slightly different technologies.

Intro to 3D Design & Fabrication
Intro to Electronics Circuit Design
Intro to Rocketry
Intro to Full-Stack Web Development
Intro to Hacking & Cybersecurity
Intro to Mobile App Development
Intro to Creative Design in Virtual Reality
Intro to Graphical Application Design
Intro to Autonomous Vehicle Control & Simulation
Intro to Remote Monitoring & Control w/ Arduino
Intro to 2D Design: Adobe Illust. & Laser Cutting

Teaching in First Year Design is at minimum a two-quarter commitment. Prospective student-teachers apply to the program as a team with a course topic proposal and culminating project prototype. If accepted, they enroll in Lead by Design to refine the culminating project experience and develop the course. Faculty associated with the makerspace facilitate this application process through a series of informational sessions and office hours in the quarter preceding LBD. They brainstorm ideas with students, help them build out projects, and often serve as matchmakers to form teaching teams. Students come to these sessions motivated to bring what they perceive as needed skills to their fellow students, recognizing that they may become teammates or club members. Many potential student-teachers are looking to formalize their lab's or club's informal onboarding that they use to train new members so they may materially contribute to project work. While a single upper-division student has successfully developed and taught a course independently, we recommend teaching as a team.

Successful teaching teams who complete LBD are hired to teach FYD in a later quarter. Each team is allocated a pool of 220 paid hours/per quarter as student-teachers which they distribute among members depending on roles and availability (usually equally). Occasionally, new FYD course ideas require additional paid hours to develop the needed infrastructure for a first time offering. After teaching their course, teaching teams debrief with faculty to capture course challenges and successes, encouraging reflection and self-assessment. Many choose to teach again in another quarter and/or return to LBD as a paid Pedagogy Coach to mentor new teaching teams. In this role, they can work directly to onboard new student-teachers to iterate and refine their course for the next offering.

III. Lead By Design Course Structure and Features

A. Course flow

Lead by Design acknowledges upper-division undergraduate students as leaders in their technical area(s) of expertise, a position that is refined through teaching. Therefore, learning outcomes in LBD are topic agnostic and focus on pedagogical practice, professional skills, and inclusive course design. Its pedagogical framing is largely informed by Kolb's cycle of experiential learning combined with constructionist learning theory, afforded by its positioning in the makerspace. The class itself follows a high-structure framework that mirrors the FYD course template; teaching teams are immersed within active- and experiential-learning practice while they create their course's learning artifacts.

Each week of the LBD quarter explicitly develops concepts that support a more engaging and approachable classroom environment through a cycle of discussion, practice, and reflection. Loosely, early topics focus on *backwards design* (in both engineering and instructional design) and *how learning works* while introducing agile project management. Mid-quarter concepts emphasize *active-learning practices* which include classroom *facilitation strategies* and *formative assessment*. Towards the end of the quarter, we concentrate on reframing strategies from the lens of inclusivity through *non-violent communication* and *constructive feedback frameworks*. Due to the nature of the course, no concept is confined to one single week; rather discussions recur throughout the quarter as student-teachers internalize understanding through practice. Refer to Table 2 for a rough list of weekly learning goals.

TABLE II
THE HIGH-LEVEL CONTENT PROGRESSION IN LEAD BY DESIGN LAID OUT AS WEEKLY LEARNING GOALS. WHILE SPECIFIC CONCEPTS OR SKILLS ARE EMPHASIZED IN A PARTICULAR WEEK, THEY RECUR AND REPEAT THROUGHOUT THE COURSE.

Week	Topic-Specific Skills & Concepts
1	Backwards Design & Eng. Notebook
2	Eng. Design Cycle; SCRUM & teaming; Learning Outcomes
3	How Learning Works; Active & Experiential Pedagogy
4	Assessment-driven design; UDL; grading teams
5	Teaching Takeover (Practice)
6	Disciplinary Communication; Equity in teams
7	Facilitation Strategies
8	Teaching Takeover (Practice)
9	Non-violent communication & Feedback practices
10	Inclusive Pedagogy; FERPA

Teaching teams begin the quarter with an introduction to backwards design and Bloom's taxonomy, which they apply in their course design: by finalizing the construction of an example artifact that represents what learners build during their culminating project experience. This artifact will be the means to showcase student learning, evincing the success of FYD in achieving its outcomes. It also serves as a roadmap for learners in FYD; teaching teams present the project and the example artifact on the first day of their class. Similarly, teaching teams clarify their own direction in LBD by constructing the culminating artifact first, allowing the needed project competencies to frame their instructional design. This practice makes explicit assumed knowledge or skills; teaching teams identify key learning outcomes (that may have initially been overlooked), estimate the time needed to construct the artifact, and articulate standards and expectations for their learners - all of which impact the rubric. The practice of backwards design in LBD is critical for the success of FYD. Teaching teams who do not take sufficient time to build out the culminating project later lead a class without a clear example of success for that topic, leaving learners to guess about their own capabilities.

Once they know where they are going, teaching teams decompose high-level learning outcomes into weekly learning goals that incrementally build content knowledge and skill toward the final culminating experience. In this way, they also practice backwards design at the level of individual learning activities: they 1) identify learning goals, 2) consider ways for learners to demonstrate those goals and be assessed, then 3) design the relevant artifact/activity/learning environment. LBD uses a weekly sprint structure to meter FYD course development; teams create and test two weeks' worth of FYD content during the weekly sprint (leaving room for revision). Agile practices are well-suited for LBD as it provides a project management structure that allows teams to easily pivot and thus quickly learn from failure through reflective processes.

B. Weekly Structure

The curricular programming for each week of LBD follows a repeated structure, creating a familiar tempo that scaffolds learning and teaching team productivity. The class meets twice a week for 95-minute sessions. Day 1 reinforces new concepts illustrated in Table 1 and is thus more faculty instructor-centered. In contrast, Day 2 is student-centered and dedicated to teaching team practice. Teaching Takeover weeks are the exception, more about this below. Each new concept is initially introduced through a prelab assignment that flips the classroom; student-teachers read journal papers and other articles or watch videos, then complete a quiz. We build on these topics in class on Day 1, first with a prelab review and then an example activity that concludes with a making-meaning discussion on why, how, and when teaching teams might use that flavor of active learning in their own classroom. On Day 2, teaching teams present or practice teaching a sample artifact from their ongoing sprint to gain feedback from their peers. Outside of class, teams execute their sprint by creating or updating learning artifacts based on these new insights; FYD course development serves to synthesize their learning for that week. At the end of the week, student-teachers are given multiple avenues for reflection: as a team through sprint reviews and retrospectives and individually by responding to a weekly reflection prompt in their engineering teaching notebook.

LBD leaves significant space for teaching practice, adopting an experiential approach to instructional design through social learning. Every week, teaching teams test their artifacts on "students" to gain needed critique, logistical feedback, and advice. In Day 2 class, these test students are their LBD classmates, allowing different teaching teams to interact and see how others have designed similar artifacts. Weeks 5 and 8, however, are reserved for *teaching takeover*. During these weeks, each teaching team is assigned its own teaching classroom with a small set of test students, which may include faculty, Pedagogy Coaches, and/or volunteer students. Over the course of the full week, they teach an actual week's worth of content from their FYD class (weeks 1 and 2, respectively). Test students are "enrolled" in the course: they complete prelabs and other homework, take part in class activities, and receive feedback on assignments. Test students then debrief with teaching teams and provide scaffolded feedback via a worksheet. Although these weeks are often stressful for the teaching teams, they find the experience valuable – it is their favorite activity in LDB. They use this week to iron out the kinks and figure out what works and what doesn't work for them, both in and out of the classroom. Did the activities achieve their goals? Were learners engaged or confused? What should other student-teachers do while one person is presenting? Teaching teams gain insight into their timing, become familiar with using classroom tools, improve communication and facilitation practices, and generally become more comfortable being in front of the classroom and making dynamic teaching decisions.

C. Key Features and Activities

We structured LBD to showcase diverse approaches in active learning and formative assessment, equipping nascent student-teachers with a toolkit of strategies and techniques they could deploy in their own classrooms. By being transparent with the reasoning behind activity designs - including when things don't go as planned - we help student-teachers build the confidence to execute both a carefully planned activity and a spur-of-the-moment idea. All learning artifacts used in LBD are intended to be utilized in FYD, though only after teaching teams take ownership of the construct and modify it towards their own goals. Aside from the ubiquitous think-pair-share, three learning activities from LBD have emerged to be the most impactful for teaching teams. The first sets the stage for what active learning means while the other two directly translate into the FYD classroom.

1) Comparing Approaches: Early in the LBD quarter, we dedicate a full Day 1 session to a modified version of the Exploratorium's Institute for Inquiry "Comparing approaches to hands-on science" [14]. Students work in pairs to complete two stations: Station A, which is handout-based and teacher-centered, and Station B, a student-centered design challenge. Afterward, we come together as a class to unpack the benefits and challenges of all 3 "stations" and discuss the context for when each might be more effective. Completing this activity early in the quarter establishes a foundation for reference regarding how learning works, how certain approaches engage some learners but not others, and how the design of teaching activities shapes the feeling of the learning environment.

2) Unbuild-it: *Unbuild-it* activities involve "taking something apart to understand how it works and then putting it back together." Essentially a form of reverse engineering, we reveal the designer's intentions by dissecting a product from its final form. In LBD, this activity serves to reverse the approach to backwards design. We use unbuild-its to critically analyze completed learning artifacts, gaining insight into the instructional designers' intended learning outcomes. We employ the unbuild-it activity at least twice during the LBD quarter: once to understand the reasoning behind the high-level structure of a past FYD class and again to unpack individual active-learning activities. For the former, we examine the culminating project prompt in Canvas, find key learning outcomes, then attempt to frame a full 10-week course flow by its weekly learning goals. We then compare our design with the original and discuss the rationale behind certain decisions.

The latter application of the unbuild-it takes the form of a Gallery Walk. Student pairs rotate through stations to complete three activities from past skill-building classes. They first experience the activity as learners, then evaluate its efficacy using a handout. The class then reconvenes for a making-meaning discussion that considers *when* the activity should be used (early learning or later), *what* the actual learning outcomes are, and if these outcomes align with the original designers' goals. The handout used to frame this discussion is based on the teaching takeover feedback worksheet and prompts participants to:

- Characterize the learning environment by placing the activity somewhere on these spectra: fun/boring, overwhelming/simple, student-/teacher-centered, etc.
- Recognize what learners may be feeling and consider that different learners might experience the activity differently.
- Consider how the activity bridges current learning to students' past experiences.
- Recognize opportunities for assessment.
- Identify the learning outcomes and decide if they match the original designer's intentions.

3) Guide Co-creation: This activity is completed early- to mid-quarter in LBD. At a certain point in most FYD courses, learners are expected to follow standards for practice relevant to that class's engineering topic. These standards, or "rules," may take the form of guidelines for best practices, tips and tricks, troubleshooting techniques, or safety procedures. Rather than simply telling learners what these are, we scaffold their experience(s) with the topic and then have the class collaboratively construct a Guide as a repository for these guidelines. This approach ensures that ownership stays with the learners, while instructors facilitate completeness. Guides are intended to feature prominently for the duration of the course; they remain displayed on walls or whiteboards so that learners can continually add new rules as they discover them. To introduce student-teachers to the concept in LBD, the class co-creates a "Style Guide for Slide Presentations" after teaching teams have already created a few slide decks for their classes. In this variation of the activity, we first critique slides from an internet source. After naming what they liked and disliked, we co-construct the Style Guide then test it on their own slide decks (which usually follows some rules but breaks others). The Guide serves as an easy-to-access reference for designing "good" classroom slides, a standard defined by the students themselves.

D. Space and Opportunity for (non-optional) Practice

As discussed earlier, positioning this series of courses within the Makerspace affords the benefits associated with makerspaces: a more casual and collegial atmosphere, freedom to take risks and learn from failure, enhanced creativity in making meaningful artifacts, among others. Our Makerspace classroom hosts workshops, passion meetups, and FYD/LBD classes. It is a highly configurable space with a limited capacity of twenty-five and is uniquely administered by Makerspace staff rather than the registrar; no other classes may use this room. This allows student-teachers to make *their* classroom more comfortable and approachable for learners by adding personal touches that may persist for the duration of the quarter. Some examples include: the Guides generated from the activity mentioned above, a component graveyard, or little rubber ducks whose numbers seem to grow weekly. By practicing in the space where they will teach, student-teachers build confidence over the LBD quarter, developing the agency to experiment with and create new approaches to classroom learning. Teaching teams have keycard access to the room so they may develop and practice their class activities or host team meetings at times that are convenient for them. Furthermore, all course equipment (e.g., 3D printers, play dough) is stored in the classroom or an adjacent room so it too is always accessible, making ad hoc demos and activities possible. All the while, students are operating under the supervision of Makerspace staff. The efficacy of this program would be inhibited without this dedicated classroom space and support of the Makerspace staff; however, this feature inherently limits program scalability.

IV. Assessment and Results

A. Methods

This evaluation of Lead By Design will inform a longitudinal study on the efficacy of the program as a whole in fostering sustained communities of practice among mixed-year undergraduate students. In this study, we employed a grounded theory approach [15] to identify themes prevalent among the learner and student-teacher populations. Insights gained from participant feedback on First Year Design courses provide indirect evidence of successes and areas for improvement within Lead By Design, providing direction for the program to better achieve its goals:

1) To create a more welcoming and inclusive learning environment.
2) To establish a more diverse group of mentors skilled in equitable leadership.

The data for this analysis was collected from quantitative and qualitative instruments as well as internal and external observations, covering a combined total of 20 offerings of FYD and LBD over four academic years:

- An anonymous post-First Year Design survey administered during the last class of the quarter (n=90). Likert items and open response questions prompt participants to assess and reflect on their own skills growth, their intentions for declaring a major in engineering, as well as the efficacy of the different FYD instructional features. The initial review of this data is reported elsewhere [16].
- Student Evaluations of Teaching for both First Year Design and Lead By Design courses (n=48).
- Lightly structured interviews and post-teaching discussions with student-teachers and learners in First Year Design (n=5).
- Documented perspectives of student-teachers from student-authored written proceedings (n=6) [17].

B. Overview of Findings

Demographics: Demographic data across the four years show that the program establishes a learning environment that is attractive to a diverse cohort of students. First Year Design courses consistently reach capacity with a waitlist, while student interest in teaching FYD is growing faster than we can scale. Students formally enrolled in both courses are more gender-balanced than the overall student population at our School of Engineering and represent a variety of disciplines from both within and outside of engineering:

TABLE III
A comparison of demographics and majors for participants in Lead By Design and First Year Design programming, compared to the School of Engineering as a whole. Notably, Lead By Design attracts student-teachers from outside of engineering to collaborate in teaching teams.

Indicator	LBD	FYD	School of Engineering
% of Female Identifying or non-binary	30%	36%	20%
# of majors represented	12 (7 from Eng)	>30	11 total possible

Moreover, these students continue to remain affiliated with the program over multiple quarters. Lower-division learners from FYD often return to take a different topic, join the teaching team to reteach the same FYD, or form a new teaching team with an original topic proposal. Interestingly, former learners also engage with the program in other roles, as outreach interns or test-students during teaching takeover.

At the time of writing, the program has supported 35 distinct student-teachers in teaching a FYD course. 10 of these have taught multiple instances of their FYD course, 7 served as Pedagogy Coaches for new teaching teams, and 12 were originally learners in the program. Note that there is overlap in these numbers; returning student-teachers fit multiple categories.

Review of First Year Design: Through the lens of assessing LBD, descriptive statistics of quantitative survey items show that learners value the hands on and high-structure framework of First Year Design. Across all FYD classes surveyed during this pilot period, learners in FYD evaluated the surveyed instructional features very favorably: the median score for all Likert items was 5 (IQR=1) with the central 50% of scores ranging from 4 to 5. As anticipated, Labs and Project-work received the most favorable responses, as did items indicative of interactions with student-teachers: availability, accessibility, comfort reaching out, and the class Slack channel. The engineering notebook was rated the lowest, eliciting marginally less favorable responses. These results are summarized in Table 4. Although overall ratings show an increasing trend over time, we cannot formulate definitive conclusions. The higher assessments of more recent offerings could reflect improvements made in LBD; however, they may also be attributed to the significant events that occurred during the period: the return to in-person classrooms post-Covid and the re-opening of the Makerspace with new facilities and support.

TABLE IV
SYNOPSIS OF LIKERT ITEM RESPONSES FROM SURVEYS ADMINISTERED ACROSS MULTIPLE FIRST YEAR DESIGN COURSES (N=90).

Instructional Item	Median	IQR
Lectures	4.5	1 (4,5)
In-class Activities	5	1 (4,5)
Pre-Labs & Quizzes	4	0 (4,4)
Labs & Projects	5	1 (4,5)
Engineering Notebook	4	1 (3,4)
Course Engagement	5	1 (4,5)
Clarity of Expectations	4	1 (4,5)
Class Q&A Sessions	5	1 (4,5)
Accessibility of Class Materials	5	1 (4,5)
Comfort reaching out for help	5	1 (4,5)
Meet & Interact with others	4	1.5 (3.5,5)
Feedback on Assignments	4	1 (4,5)
Mentor Availability	5	1 (4,5)
Slack Channel	5	1 (4,5)
Office hours & open labs	5	1 (4,5)

Inductive content analysis of qualitative items revealed more subtle themes that highlight the importance of programmatic features. Both *learners* and *student-teachers*, across topics and years, consistently valued the high-structure framework coupled with the accessibility and approachability of student-teachers. Responses affirm the progressive course structure as effective in preparing learners for later topics, but also in elucidating confusion so that it could be promptly addressed. This learner's open response captures the sentiments of many others across different classes and years:

> *The entire class was designed very well, and in a perfectly streamlined manner. The prelabs adequately prepared me for lectures, the lectures prepared me for the in class assignments, the in class assignments helped me test what i'd learned and allowed me to recognize things i didn't fully understand (in time to ask about them during class), and all of that prepared me for the labs, which in turn prepared me for the next week.*
>
> –Learner in F20 Intro to Electronics Circuits Design, survey open response

The collegial classroom, explicitly cited by learners as supportive, meant they were less reticent to reach out for help when they found they needed it. Students described the multiple avenues for feedback – class time, office hours, Slack channels, and Canvas – as "*easy*," "*always available*," "*responsive*," and "*non-committal*." Significantly, support was not only readily available from student-teachers trained to give constructive, just-in-time feedback, but also from their peers, evincing the formation of trust between learners. Learners' responses suggest that the collaborative and slightly competitive atmosphere (coded separately) engendered by in-class group challenges and Kahoots supported, rather than diminished, the collegial and creative environment.

Successes in Lead By Design Programming: Learners' favorable responses to First Year Design indirectly speak to the efficacy of Lead By Design in preparing teaching teams to create an active and welcoming learning environment. Although there have been hiccups and instances of learner confusion that necessitated last-minute interventions by faculty working behind-the-scenes, these were not atypical for the first offering of a new course. Learners reported difficulties relating individual concepts from the prelab to classwork, frustration with absent team members, and advised changes to the timing or sequencing of concepts; feedback that is addressed as the course progresses or in the next offering. Students enrolled in LBD conveyed analogous reviews as learners in the Student Evaluation of Teaching survey, which has helped to streamline LBD's required readings and structure, leading to positive outcomes appreciated by both the learners and student-teachers:

> *I saw that the tutors[student-teachers] were using different active learning methods and collaborative activities. It was easy to observe because they were professional and had a lot of confidence. At first, I didn't know that they were students.*
>
> –Learner in F23 Intro to 3D Design, post-class interview

This learner's sentiment is echoed in responses from student-teachers who participated in the program in some capacity before Lead By Design became a for-credit course in Winter 2023, rather than a paid internship (more on this below). These returning student-teachers observed improvements in overall learning after applying the frameworks taught in Lead By Design.

> *The students were mostly quiet and didn't participate as much as after I took Lead by Design. I noticed that after we redesigned the class, students responded better to the type of teaching, and they*

> *were more engaged with the material and with each other.*
>
> –Repeat Student-Teacher of Intro to 3D Design, post-teaching interview

An additional theme emerged from both learners and student-teachers, who emphasize the importance of class sizes remaining small. Learners appreciate being able to form relationships through in-class collaborations, where they "*knew everybody's name*," and, as mentioned above, valued the feeling that timely feedback was available should they get stuck. Many learners keep in contact after the class ends – both with fellow students and student-teachers – a stark contrast to the typical learning environments found in lower-division classes. Repeat student-teachers notably remarked that fewer enrolled learners dropped overall when FYD design no longer allowed auditors to amplify class numbers.

> *I've taken many lower division classes with hundreds of people and a lecture style. This class is super hands-on, and each week, they had activities that made the class worth attending. I was able to talk with a group to discuss problems and solutions.I enjoyed the opportunity to collaborate as much as I was able to because we don't get a lot of that in lower-division CS classes.*
>
> –Learner in F23 Intro to 3D Design, post-class interview

V. Discussion

A. Challenges to scalability

Our initial approach to positioning students as teachers for Makerspace skill-building classes functioned more as an internship. Faculty hired students over the summer to adapt a class model to support their proposed topic. This format did result in more approachable courses comprising hands-on activities for new students and was successful in creating communities of interest - especially during COVID and remote teaching - simply by virtue of being designed and taught by students. However, it did little to formally promote diverse thinking and equity in the classroom.

Lead By Design moved course development into the typical course structure, a more familiar framework in which students operate, i.e., into their zone of proximal development. Student-teachers are therefore subject to the rigor, accountability, and practice that an experiential classroom provides, while maintaining ownership of the topic being developed. In this immersive environment, we are better poised to unpack the black box perspective to learning while making practices that marginalize some learners more transparent. Lead by Design is the key to scaling our First Year Design course series to reach more learners with an inclusive and welcoming learning environment, by training the trainers in equitable classroom practices.

However, much like capstone or cornerstone courses where learners work in teams to complete diverse projects, Lead By Design is difficult to administer if viewed as a traditional class. It demands resources that exceed the typical university unit/workhour model, both for the associated faculty and student-teachers. Given the rapid pace of FYD course development, the success of teaching teams depends on prompt feedback from experienced instructional designers. The teaching takeover provides this opportunity for real-time practice and feedback while offering teaching teams a holistic view of the learning process, a perspective they must firmly establish early in the quarter. Student-teachers consistently cite this as one of the more impactful features in LBD; however, it is logistically difficult to orchestrate. Ideally, all learning artifacts would be reviewed or tested as they are developed, at least initially, to gain diverse critique and thus set the standard for subsequent work. Unfortunately, teaching teams, instructional faculty, and Coaches simply do not have the time for this level of review. Departmental Teaching Assistants have largely been unsuccessful in this role, as they are not trained in experiential pedagogy. Our recent introduction of Pedagogy Coaches as peer mentors is a genuine improvement to the course, but as students themselves, they often have substantial class or extracurricular responsibilities during the quarter - or maybe busy teaching!

Conversely, if we assess Lead By Design by its products, it may prove to be more scalable than when considered a traditional class. A single faculty member would find it challenging to design four entire courses (on average) rooted in active-learning principles over one quarter, let alone at a fraction of their percentage time. On that same note, a single teaching faculty would struggle to teach four active-learning courses during the quarter and still provide the same level of accessibility, guidance, and personalized support. In leveraging this approach, we modernize and broaden our offerings within the School of Engineering while utilizing faculty time more efficiently and effectively.

VI. Conclusions and Future Work

We view the interplay of mixed-year undergraduate engineering students coupled with ownership over topics and projects as instrumental in fostering authentic learning communities of practice. Lead By Design scaffolds peer-led learning typically prevalent in less formal spaces, into the curricular programming without diluting the sense of ownership and interest that often drives these activities. First-year students practice as engineers in a more casual and low-risk environment due to the positioning of their upper-division peers as the teachers. As "experts," student-teachers provide more accessible, approachable, and empathetic feedback and mentorship. Both cohorts undergo critical identity work; they are recognized as, or to soon become, experts in a self-selected area of engineering.

Future work focuses on scaling these experiences to ensure they are accessible to more learners and potential student-teachers. As First Year Design is being embraced by engineering departments, questions around equitable access arise, particularly concerning logistics and workload burden for all participants. Is it possible for First Year Design to be a major requirement while preserving enthusiasm and ownership among both the learners and student-teachers? Could more formality permeate into the casual learning environment, changing the dynamics of the makerspace classroom? Understanding these subtle shifts will be critical if we are to build inclusive and sustaining communities of practice that support diverse engineering identities. Moving forward, we are looking to embed systematic data accumulation methods, such as notebook prompts and reflections, within the classroom structure to surface the ongoing identity work of our nascent engineers.

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