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Building the Engineering Identity of the Lower-Division Engineer: A Formal Model for Informal Peer-to-Peer Mentorship and Student Leadership through Undergraduate Student-Led Experiential Learning

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Building the engineering identity of the lower-division engineer: A formal model for informal peer-to-peer mentorship and student leadership through undergraduate student-led experiential learning.

Abstract

In this academic practice proceeding, we present a model for a series of approachable, skills-based courses aimed at supporting constructive engineering identity work among learners in their first year – by being largely designed and taught by upper-division undergraduate students. The students propose the learning outcomes for these First Year Design courses to target skills - both *technical* and *professional* - that they identify as valuable when navigating theory-based coursework and practice-focused extracurricular activities. Student-teachers build their course from a high-structure template centered in active and experiential pedagogy, where learners are initially "set up" with content knowledge and skills practice before being "let go" to navigate the entire engineering design cycle on a team project. Through this peer-to-peer active learning model, we not only provide real-world context for what it means to be an engineer to our lower-division nascent engineers, we also cement the engineering identity of our upper-division student-teachers by celebrating their skill as experts. Thus far, course assessments look promising: learners achieve complex team project artifacts; they value working and learning as a more diverse cohort across disciplines; they are better able to relate to engineering tracks with many joining engineering clubs; and they see themselves in the student-teachers. Many learners go on to propose and teach a First Year Design course themselves. Though this program is not without its challenges, these preliminary results suggest we are training the next generation of student-leaders, one that is more diverse and fluent in what it means to be an engineer.

Introduction: what does it mean to be inclusive in engineering education?

Active learning coupled with high-structure course design has proven to benefit all learners in the STEM fields and has the potential to close achievement gaps for minoritized and under-resourced learners [1-6]. Active and experiential learning asks students to become active participants in their knowledge construction through activities that often better align with professional engineering practice. This contrasts with didactic approaches traditionally utilized in university engineering classrooms, affording learners more opportunities to practice within their intended discipline [1-5,7-9]. Synergistically, high-structure learning makes participation in these opportunities to practice engineering distributed and non-optional; learner time, both in and out of the classroom, is intentionally scaffolded by the instructor rather than the student. Thus, employing active pedagogy within a transparent course structure helps prepare all learners for self-efficacy in the field while creating space for constructive identity work, as it:

- Helps learners establish work routines and efficient habits through direction, time blocking, and *accountability.*
- Structures time for low-stakes *practice,* often with facilitated feedback.
- Establishes clear objectives for learning with multiple avenues to demonstrate that learning.

- Holds learners responsible for (and supports them in) acquiring foundational knowledge to build from (e.g., Flipped Classroom, Just in Time Teaching, Jigsaw support ownership through accountability).
- Engages more learners via class activities based on relevant, real-world, and contextual applications of STEM concepts.
- Builds a community of practice through scaffolded group activities and peer-to-peer interactions where learners learn from each other and construct ideas collaboratively.

The described pedagogical model contains the ingredients to create a truly inclusive learning environment through *rigor*, *accountability*, *practice*, and *ownership*. If designed with intention, it can potentially engage all learners in a perception of engineering that aligns with their individual values and goals [2,5,9-11].

As can be gleaned from the "ingredients" above and further supported by literature on engineering identity work, simply offering more opportunities to "do engineering" is not enough to bolster the development of an engineering identity, which correlates to persistence in an engineering field. More engineering-related knowledge, exposure, and experience help build confidence, preparedness, and connections with others in the field – all constructive aspects in individual identity formation *in general* [6,9-11]. However, the learning environment in which these connections are made can (and often does) perpetuate the marginalization of minoritized learners, negating the benefits of these constructive factors or even detracting from the formation of an engineering identity (i.e., "I am not an engineer; I am not part of this group") [6,10-12]. For learners, cultivating a sense of belonging in engineering requires an engineering learning environment structured to be inclusive, one that challenges stereotypical boundaries and perceptions that disadvantage female-identifying, underrepresented, and other minoritized groups. As high attrition rates among minoritized learners are often attributed to poor performance in introductory classes [2,6,13], it is crucial that developing engineers experience early engineering-related successes and a welcoming campus culture in their first year at university [9,11].

In our School of Engineering (i.e., across departments and disciplines), we are formalizing an undergraduate engineering model that creates sustained learning communities of practice by giving our undergraduate students agency over what and how engineering design is taught. This proceeding first presents the intentional design of a learning environment housed in inclusive and constructionist principles, one that is heavily influenced by the communities (multidisciplinary, mixed-year students) and spaces therein (making). We then describe the course template student-teachers work from to yield high-structure First Year Design courses and provide examples of common practices implemented by the student-teachers as well as emergent features critical to the courses' success. Finally, we discuss preliminary assessments and course evaluations that surface these successes and ongoing challenges, framing our next steps for more equitable programming.

An Inclusive Model for First Year Design

Structurally supporting Engineering Identity Work

The objective of the program model and its associated courses, “Lead-by-Design” and “First Year Design,” is not only to bring more opportunities for engineering practice to lower-division undergraduate students but to build learning communities that support the ongoing identity work of developing engineers as they navigate the university ecosystem. Lead by Design positions upper-division undergraduate students as leaders in their area(s) of expertise. Prospective student-teachers apply to the program as a team with a course proposal; those accepted enroll in the quarter-long, 5-unit (15 workhours/week) Lead by Design class. Here, teaching teams work from a high-structure course template to design, practice, and iterate course content, which they are hired to teach in a subsequent quarter as a 3-unit (9 workhours/week), First Year Design. Thus, the specific topic offered varies with the intentions and backgrounds of the teaching team. Students participating in Lead by Design develop their course’s learning artifacts while they experience and learn active and experiential learning pedagogies, non-violent communication, and Agile project management. While Lead by Design is not within the purview of this Proceeding, it does provide some context regarding this paper’s subject: First Year Design.

With First Year Design, we intend to provide lower-division undergraduate students with experience doing engineering in a more casual, low-risk environment. Here, we bring formative engineering experiences typically found later in an engineering program to first-year learners as opportunities to apply and showcase content knowledge, learn (and recover) from failure, and traverse the full engineering design cycle through a team-based culminating project. The casual, low-risk learning environment to “do engineering” is reinforced by physically situating the course within our Makerspace with the added twist that developing engineers are taught by upper-division undergraduate students. In this way, undergraduate students work and learn alongside their peers. Mentorship, support, and feedback are much more accessible as fellow students are more easily approached and more empathic to the learners’ situations than typical faculty.

We view the interplay of lower-division and upper-division undergraduate engineering students combined with the *rigor, accountability*, *practice*, and *ownership* afforded by the course structure as instrumental in developing authentic learning communities of practice. Lower-division undergraduate students see firsthand what they will become experts, within a few years or perhaps realize they may already be there. These learners can decide what they want to learn by selecting between course offerings and how they want to use their learning: is this skill needed for a personal project, or are they intending to join an engineering club? Moreover, in many First Year Design classes, learners can propose a project for their culminating final experience based on their own values and goals. Perhaps most importantly, lower-division students gain access to peer networks and role models, building engineering-related connectedness or, in other words, a sense of belonging.

Upper-division students also undergo critical identity work. Their ideas, skills, and perspectives are celebrated and have substantive impact as a course within the School of Engineering, where they share their expertise with others. These undergraduate teaching teams create content they feel is needed within the curriculum and deliver it in a way that would have been more efficacious for them as learners. They serve as guides for the next generation of student-leaders and build relationships that frequently transcend the boundaries of the class.

The makerspace as an intersection for collaborative teaching and learning

In the academic year 2019-2020, we identified a synergistic opportunity between our own diversity goals for our burgeoning Makerspace and the activities of the students when given agency over activities within that space. At that time, the Makerspace curriculum comprised hands-on learning modules designed to quickly provide any learner, regardless of discipline, access to the relevant concepts and skills needed to design and construct a prototype toward their project goals. The idea was to build confidence in using the space and its tools while supporting multidisciplinary discourse. Concurrently, student leadership within the Makerspace, namely from student clubs, were (and still are) volunteering to teach incoming club members the basic skills needed to actively contribute to the clubs' project implementation. In both scenarios, the motivation was notably the same: to build an "engineering toolkit" of content knowledge, technical proficiency, and professional skills for lower-division students so they have the confidence to pursue their interests in complement to the academic setting. This observation posed the question: can we become more inclusive and equitable by formally supporting these student-leaders in their curricular interventions?

Course Template:

We developed the course model for First Year Design over multiple years of collaboration with students as teachers. This template generates a high-structure course with transparent learning objectives while leaving room for ownership of topics covered, specific learning outcomes and equipment checkoffs, activities employed in the classroom, and the culminating project artifact. First Year Design offerings are open to all students and satisfy a General Education (GE) requirement; learners enroll based on their interests and ambitions while gaining needed GE course credit. Since the initial deployment of this model, undergraduate student-teachers have designed, developed, and taught* the First Year Design courses presented in Table 1).

We designed First Year Design to support any learner in developing a toolkit of professional skills alongside engineering content knowledge and technical skills specific to the course topic. We assume no previous experience; early scaffolding "sets them up" with foundational content and practice through active learning artifacts. In the later weeks, we "let them go" to use their toolkit in a team-based, design-build-iterate culminating project experience. Figure 1 below depicts this high-level structure for two example courses. All the while, learners are guided by accessible peer role models as student-teachers. The faculty instructor of record operates behind the scenes to support the teaching teams, though learners know who they are and frequently see them around. While the specific learning outcomes vary based on the skills-based topic being offered (abridged in Table 1), First Year Design courses uniformly emphasize the following learning outcomes within the given structure:

- Practice disciplinary documentation using an engineering notebook;
- Understand and apply technical documentation to appropriately select materials and components (datasheets, whitepapers, industrial application notes, etc.);
- Navigate the engineering design cycle through iterative design and version control;

- Effectively collaborate in a cross-disciplinary team to produce a tangible artifact;

Evaluate product properties and features to meet functional design requirements under identified constraints.

Table 1: First Year Design topics developed and taught by undergraduate student-teachers since the 2019-2020 academic year. Each course offering prioritizes proficiency in technical skills showcased through a culminating team project.

Course Title	Topic-Specific Skills & Learning Outcomes *(abr.)*	Culminating Team Project
Intro to 3D Design & Fabrication	CAD SolidWorks; basic & advanced tools 3D Printing with check-off 3D Printer repair & troubleshooting Rapid prototyping	Open Project within a creative or technical track
Intro to Electronics Circuit Design	Foundational Electrical Theory Circuit Design & Troubleshooting Electronic Test Bench Measurement EDA Toolchain with Eagle; PCB Layout Soldering with safety check-off	Buck Circuit with 555 Timer to power and control a variable speed, rotating desktop fan
Intro to Remote Monitoring & Control	Foundational Electrical Theory Circuit Design with Sensing & Actuation Programming Fundamentals Data Collection & Analysis Embedded Systems with Arduino	Greenhouse plant environmental monitoring system with regulation
Intro to Full-Stack Web Development	Front-end Development: HTML, CSS, JS Back-end Development: NodeJS, AWS GitHub & Version Control Test, document, debug code	Interactive web application with third party API calls and data visualization
Intro to Hacking & Cybersecurity	Basic Linux & Command Line Analyze & Interpret Forensic & Network Data; Steganography Advanced research skills & problem-solving Disciplinary Communication: Write-Ups	Series of mock Capture the Flag competition challenges
Intro to Creative Design in Virtual Reality	GitHub for collaboration & hosting Design & Deploy VR interactives: ShapesXR UI Design: Design Thinking & Storyboarding	Design & create a prototype VR application
Intro to Graphical Application Design	UNIX Command Line Qt & Networking; GUI programming Intro to OpenCV GitHub for collaboration & version control	Networked Security Camera with facial recognition and an interactive GUI
Intro to Autonomous Vehicle Control & Simulation	Software development in Linux Autonomous driving algorithms Design multi-sensor systems in ROS Planning, Perception & Control	Optimize Follow the Gap deployment with selected advanced topic; create your own prelab & lab

* Note that some of these classes were taught multiple times. Other topics were developed but have yet to be taught - these are not included here.

The high structure of First Year Design, made transparent to learners and emphasized from the beginning, helps to create a more participatory learning environment of rigor, accountability, practice, and ownership. Learning is distributed into weekly modules that provide diversified opportunities for non-optional participation and rapid feedback, which, in turn, supports formative assessments and responsive, dynamic teaching. Early modules foster skill development, while later modules build in complexity to focus on integrating these newfound skills and knowledge. Within each week's module, learning also builds towards articulated learning goals made known to learners via a Canvas Overview and Wrap-up, agendas during in-class activities, and (light) assignment rubrics. The repeated weekly structure creates a familiar tempo that fosters both learner and student-teacher self-efficacy, guiding learners while they build up their engineering project portfolios. We provide examples of the Canvas Learning Management System artifacts in the figures below.

Figure 1: Canvas depiction of the full course module structure of two First Year Design offerings, as designed by student-teachers: Intro to Cybersecurity (Left) and Intro to Creative Design in Virtual Reality (Right). Both courses follow a high-structure layout that sets learners up in the early weeks for a team-based, culminating design-build project in the later weeks.

Set Them Up:

In the early "set them up" phase, which may cover the first 4 - 6 weeks of the quarter, depending on the course, we focus on individual development through community. As described above, the typical weekly module also follows the "set them up" and "let them go" theme to create a recurring cycle of activities that distributes learning over space and time. Learners individually complete out-of-class assignments to build their confidence and accountability. This practice also establishes a more uniform foundation of content knowledge and skill across learners. In-class time is more focused on building community through participatory active and experiential learning where learners collaboratively construct knowledge. Refer to Figure 2 for an example of an early-week module, as presented in Canvas.

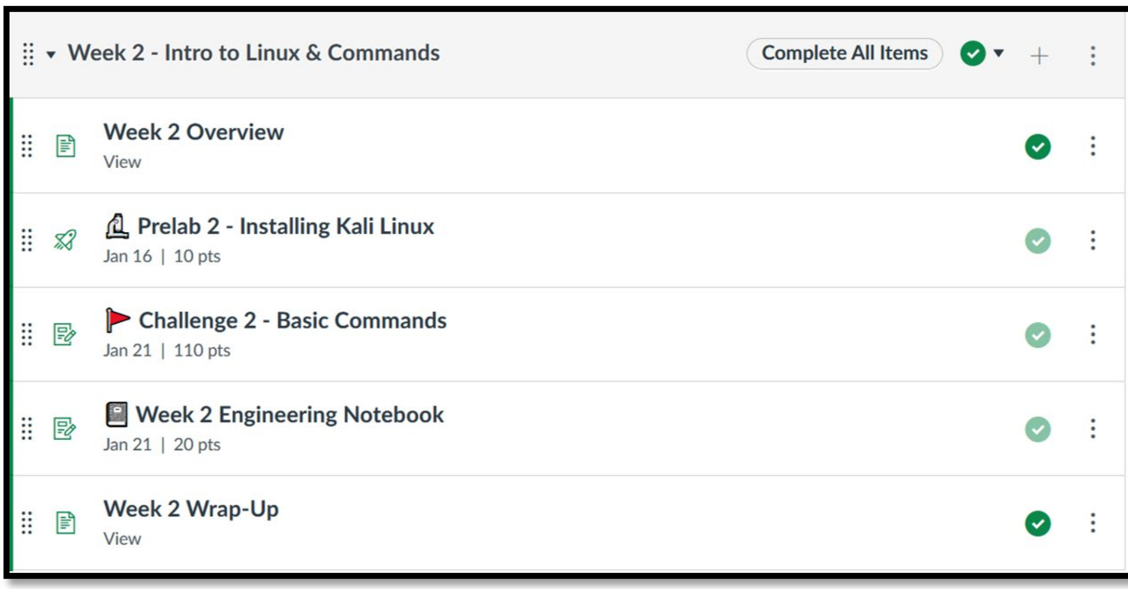

Figure 2: Example framework for an early learning module in First Year Design, as viewed by learners in Canvas and designed by student-teachers. Here, we depict week 2 of the Intro to Cybersecurity course; this framework repeats each week until learners transition to their culminating challenge in week 9 of the quarter.

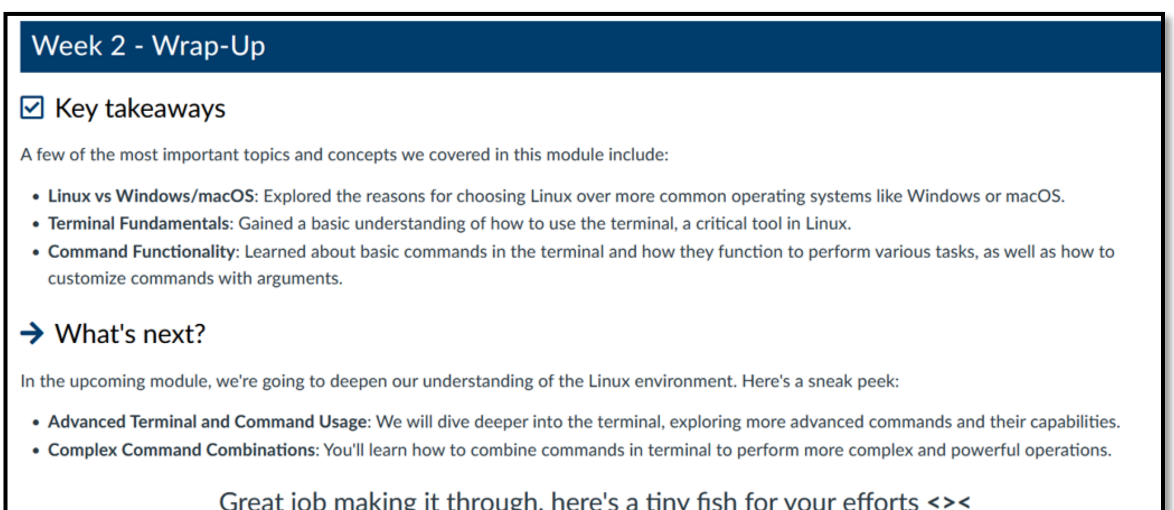

Figure 3: An example of a weekly Wrap-Up available to learners in Canvas. Student-teachers design these to reinforce the intended learning goals for the week through encouragement; notice the tiny fish as a nod to learners' successes that week.

Weekly Overview/Wrap-up: Each week begins with an orientation to the week's goals and learning objectives, available via Canvas and often reviewed during class. It identifies upcoming activities and associated assignments alongside their due dates with links, becoming a roadmap of activities leading to that week's lab challenge. If learners get lost or miss class, the weekly overview and wrap-up are always available to direct learners toward the next thing. We present an example of a weekly wrap-up in Figure 3.

Prelab & Quiz: The "Prelab" assigns preparatory content needed to complete the week's module. It serves to flip the classroom, moving lower cognitive loading activities outside of class to become a foundation for building in-class content. Prelab materials are generally sourced from already-existing content and thus do not need to be created by student-teachers; they may comprise readings, online videos & tutorials, or configuration prompts such as software download and setup. Evidence of learning is checked via a low-point value quiz with no time limit to ensure everyone comes to class prepared. The teaching team utilizes varying question types with questions phrased to emphasize key learning goals for the week and prompt personal meaning-making and reflection. These quizzes are instrumental to the learning process; they check that learners did the reading and reinforce critical information. Quizzes also make space for uncertainty and encourage learners to communicate this directly to the teaching team. We include questions such as "Is there anything you want to ask the teachers right now?" and "How can this class better support your learning?" Quizzes are reviewed during the first class of the week to solidify understanding; they are due before the beginning of that class, and there are no options for late submissions.

Pedagogically, prelabs serve as a point for formative assessment. Student-teachers review prelab responses before class and adjust the day's discussion based on learner understanding of critical content to immediately clarify misconceptions. It provides a gauge to let the teaching team know if learners are ready to move on to more complex topics or if time is better spent unpacking the fundamentals. Student-teachers are transparent with their learners about the importance of the prelab in building introductory content "so we can better learn from each other." However, they frame it as "moving the boring stuff out of class so we can do the fun stuff together," with experts (student-teachers) available for advice when *doing engineering* gets difficult.

In-class active and experiential learning: Class time is dedicated to active and experiential learning activities that exemplify prelab material in a real-world context and prepare learners for their labs. Classes always begin with "burning questions" and frequently with notebook reflection time. From there, class time is predominantly reserved for (non-optional) practice, where student-teachers facilitate activities that prompt learners to contribute their understanding of the material and collaboratively build on ideas. We list some active learning strategies employed by student-teachers in Table 2 below, presented by how we, the teaching team, frame each activity: to what degree is ownership transferred to the learner? Diverse learner participation in class activities is the key to forming a developing community of practice. The teaching team operationalizes this ideal by attempting to have learners' voices heard as often as the student-teachers; extra-credit points are given for learner in-class contributions – though the equity of this practice is unclear. All learners gain participation credit through worksheet or notebook submissions.

Table 2: Active learning strategies employed during First Year Design class. The teaching team promotes learner interaction and contribution by framing each activity with the question: to what degree are we transferring ownership to the learner? Are they being recognized for their newfound expertise? Activities flow to the right to become more student-centered.

Activity type	How participatory is it? Teacher-centered ⟷ Learner-centered			
Lecture	Q & A	Open-ended/blank slides where learners fill it out; brainteasers	Think-Pair-Share	Co-create troubleshooting Guides
Simulation / Walk-through / Demonstration	Teacher-demo while asking learners questions	Teacher-as-puppet, where the teacher only completes learners' commands	Learner-demo while asking other learners questions	Round Robin Learner-demo: different learners complete each step
Activities	Demo Stations: show a different action for equipment at each station	Paired / Group / Jigsaw Design Challenges	Equipment Check-off with a required cheat sheet	Time-boxed Lab/ project work time with periodic hints and demos

Student-teachers plan and develop these class activities in an earlier quarter, affording some testing and iteration. While designing activities that scaffold more complex theory and ideas, student-teachers are guided by the question: can learners remain engaged and have fun? During teaching team discussions and class reflections, we ask ourselves: how participatory is this class actually? Will *all* learners be engaged? How might they feel excluded? Some essential active learning practices have come from asking ourselves these questions:

- Leave time for learners to think before calling on someone to answer a question – meaning we must become comfortable with periods of silence.
- When doing activities, make sure the goal and instructions are always transparent and available to everyone via a slide or on the whiteboard.
- Try to include a timer so learners know where they are in the activity.

One strategy worthy of note is the co-creation of learner "Guides." Often, student-teachers find themselves repeatedly answering the same questions or clarifying the steps they took to build something that *works* or to discover why it does *not work*. It is not enough to model the complexities of doing engineering, which comes from years of practice and is often implicit to the practitioner. Thus, we make these complexities explicit by co-creating guides with the learners to be used when blocked. This activity usually begins around week 3, when learners have sufficient experience to reflect on the actions they, their peers, and the student-teachers take when faced with a challenge. Guides are co-constructed as ordered steps to try out to help move through the problem: learners frame the steps, and the teaching team provides insight into their ordering. Some student-teachers do this activity on the whiteboard after a reflection period and return to it throughout the quarter so learners can continually add to it as the class progresses. One teaching team is looking to print their "rules of engagement" as a poster to hang on the classroom wall. Within the different course topics, co-created Guides have manifested as: Guide to Troubleshooting Circuits, Lab Safety, Spotter Training in VR, Rules of Engagement in Cybersecurity, and more.

Out-of-Class Lab or Challenge with Engineering Notebook: While in-class activities afford time and space for practice, the module "Lab" or "Challenge" assignment, due at the end of the week, is where individual learners synthesize and demonstrate their learning. The lab carries the bulk of the grade for the module, though, unlike the prelab, there is wiggle room to resubmit for a higher grade. Lab assignments take on different forms depending on the class topic and when in the quarter they are assigned, but always include a detailed prompt with, at minimum, a simplified rubric. In general, learners construct an artifact that requires them to apply content knowledge to solve a defined problem in the lab setting. Some examples include building a stoplight circuit; using advanced tools in CAD to create a model that will fix a broken pipe mounting; designing your dream balcony in virtual reality with a minimum number of interactives and lighting ambiance; or a mini-Capture the Flag challenge. Given the availability of the rubrics, learners can prioritize their activities toward what will carry the most points if needed. As this class explicitly incorporates a course Slack or Discord server, learners start channels to ask for or give advice before the lab due date. In the leadup to the Virtual Reality Art Challenge (depicted in Figure 4 below), learners took to Discord to encourage each other's creativity and skill in VR design. The #gallery channel is full of art and many celebratory emojis.

Figure 4: Snapshots of selected learner submissions to the Virtual Art Gallery Challenge in week 4 of the Creative Design in VR course. Learners each created an immersive scene to showcase their artwork, which were then stitched together to create an art show to be experienced in VR. This art was created by learners and named. Top row, from the left: "Kirby," "Mountain Slug," "Spiderman," "Banana Cult." Bottom row, from the left: "Gentle Gollum," "Candyland." "Eevee,"" Bird."

The labs usually require learners to submit at least two items to receive credit: a picture/video/link to the physical artifact alongside scanned pages from the learner's engineering notebook. It is not the success of the artifact that dictates the grade for the lab but the notebook content, where learners are encouraged to show their thought processes, sketches, ideas, mistakes, and the evolution of their design thinking via this low-stakes modality. Student-teachers often add reflection prompts or guided questions to be answered at the end of the lab to help synthesize learning; we want to employ this strategy more consistently in future courses.

The teaching team uses the notebook to surface learner understanding and then provides direct and qualitative feedback that addresses uncovered misconceptions and encourages beneficial learning practices. It also serves as a gauge for the class, informing the formative assessment - dynamic teaching cycle; student-teachers edit lesson plans to match where learners are. Notebooks are handwritten (paper or digital) to better capture raw ideas without the ease of editing. Unfortunately, since engineering notebooks are submitted for feedback and to supporting grading, we must ask learners to write somewhat legibly, leading to a more contrived view of this professional documentation practice.

Let them Go

The later weeks focus on transferring ownership of learning onto the learners to become self-directed. After facilitated team formation, learners work in pairs or teams to take on a substantial design challenge and begin their journey through the engineering design cycle, with room for at least one substantial iteration. During these last weeks, the course reorganizes around professional practice; there are no more prelabs, lectures, or labs (Figure 5). Learners are viewed and treated as experts capable of driving the project's efficacy as a team. They are responsible for the prototype design, selecting components (which are purchased for them), and learning from their mistakes. In many course offerings, teams have the creative freedom to propose a project topic or artifact to complete, allowing teams to construct their learning around their shared histories. The crown, earrings, & webpage shown in Figure 6 are such examples.

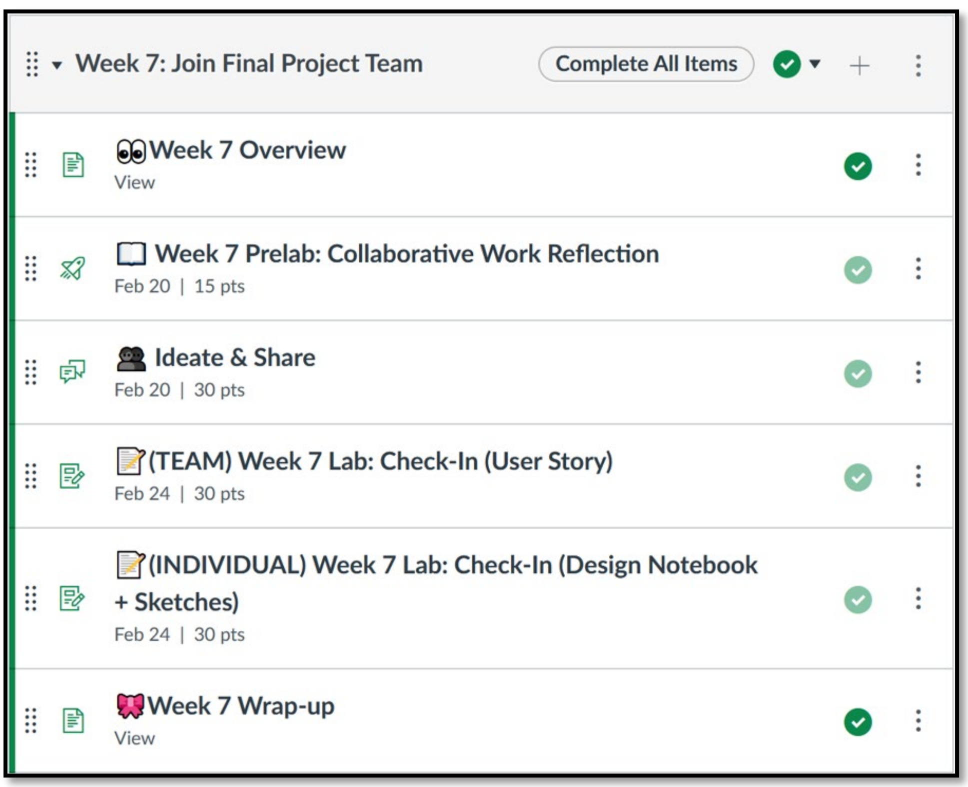

Figure 5:Example framework for a later learning module in First Year Design, as viewed by learners in Canvas and designed by student-teachers. Here, we depict week 7 of the Creative Design in VR course as learners transition from the more highly scaffolded early weeks to more independent (though as part of a team) culminating project work. In this course, the Ideate & Share discussion is used to form teams with similar goals for their final project: a prototype VR app.

During *let them go*, the high structure to which learners have become accustomed begins to fade away, though it is not completely absent. We use class time for facilitated project work where student-teachers serve as advisors. As learners have already completed equipment checkoffs as part of an earlier lab, they can independently use equipment as needed for their projects. Student-teachers keep teams on track and monitor team health through design reviews and check-ins accompanied by engineering notebook submissions, timed to mark the end of a project phase (e.g., submit your candidate CAD model to the Preliminary Design Review). During these final project weeks, student-teachers often adapt class time to the needs of their learners: some implement SCRUM practices to support teaming, while others bring in advanced bonus content or guest speakers as ad hoc lectures if teams are looking to expand their project beyond the standard tools taught in the class.

The project work culminates in a showcase as a technical presentation scheduled during the three-hour final exam period. Teams gather to present and review each other's work as colleagues, asking questions and providing suggestions. Usually, the collegial atmosphere is enhanced with pizza and snacks to frame learner successes more like a party – something to be celebrated rather than a formal requirement. The teams submit their presentation, photos/videos of the artifact, design files, and final engineering notebook pages with a course reflection and suggestions as their project portfolio at the end of the quarter.

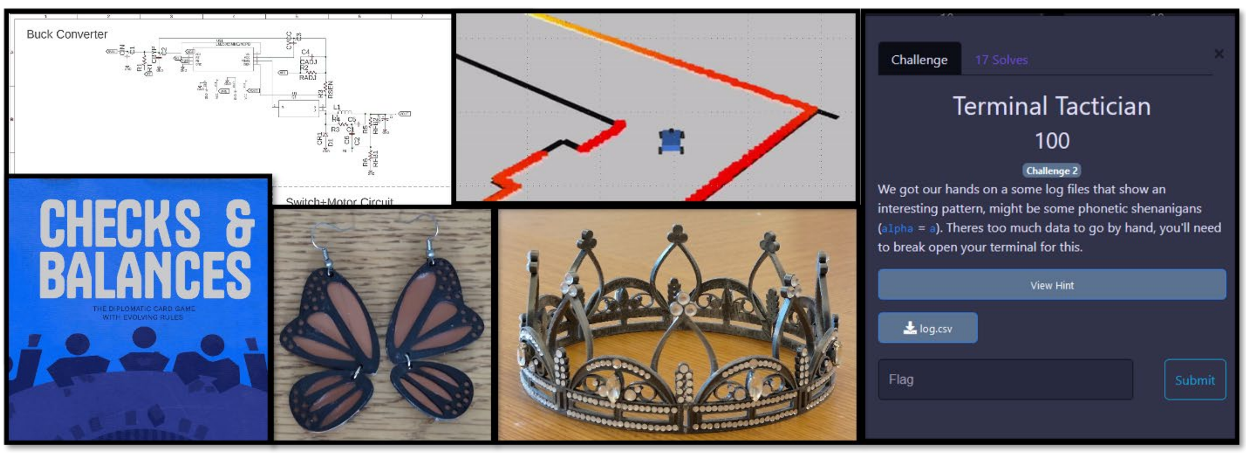

Figure 6: Example final project artifacts created by teams in the different First Year Design courses over the years. From left to right: Buck converter schematic from Electrical Circuit Design; "Checks & Balances: A diplomatic card game with evolving rules," a learner-proposed webpage from Full Stack Web Development; the 3D printed butterfly earrings and crown were proposed and developed by two learner-teams in 3D Design & Fabrication; a simulated vehicle deploying a self-driving car algorithm in Autonomous Vehicles & Control; and an example Capture the Flag challenge from Cybersecurity.

Notable features and behind the scenes

Instructor of Record: All student-led classes include a faculty member as instructor of record who mentors the teaching teams as they develop course materials and while they teach. This role is necessary to navigate course logistics and bureaucracy, leaving students to focus on teaching and learning. Perhaps more importantly, the role is instrumental in establishing and maintaining transparency regarding learner assessments. Student-teachers are responsible for providing prompt feedback to learners, but the instructor of record issues grades to avoid any perceived bias from being graded by their peers – who may already be or could become friends. The instructor of record serves as part of the teaching team and participates in weekly lesson planning where they advise on sticky matters, for example, navigating accommodations, supporting equal classroom participation from all learners, forming teams, giving encouraging and actionable feedback, and intervening when grades begin to slip; though, the faculty member usually takes over this last item. They also sit in on classes to support student-teachers in building their confidence by being available if needed and providing feedback during post-class debriefs. Often, it helps just to be there until the student-teachers hit their stride. Thus, the workload for the instructor of record is heavy at the beginning of the quarter as they set up the classroom/lab space/equipment for what is frequently a new class context, organize Canvas, attend classes, debrief student-teachers, and deal with add/drop and permissions codes.

Makerspace Classroom: The space in which these courses are taught has emerged as another critical factor in the success of First Year Design as it hugely affects student (both teacher and learner) comfort. First Year Design and Lead by Design courses are taught in a highly configurable Makerspace classroom with a limited student capacity of twenty-five. Student-teachers practice in the space in the preceding quarter, configure it as they see best for the activities of the day, and add their own flare that persists for the duration of the course, for example, the Rules of Engagement poster mentioned earlier or a corkboard component graveyard. Their ownership over the space extends to the learners, potentially becoming a constructive factor in students' identity work.

The fact that the Makerspace owns the classroom makes much of this possible. As makerspaces have the *potential* to democratize learning through low-risk activities with community support [7,8,12], their accompanying "room for failure" extends to our learning environment. Additionally, these are not registrar-governed rooms and have Makerspace staff oversight; student-teachers can safely access the space almost whenever they wish to set up, try out new demos, hold office hours or teaching team meetings, etc., which is significant given their busy schedules. Furthermore, the equipment for their class topic is permanently (for the quarter at least) housed in an adjacent room, making ad hoc class or office hour demonstrations possible. Makerspace administration means equipment is maintained and repaired by Makerspace employees, a frequent necessity due to heavy usage. It also means learners can access equipment more flexibly with some oversight if student-teachers are unavailable.

Preliminary Results and Lessons Learned

Promising Results:

Preliminary results extracted through quarterly exit surveys, student evaluations, learner and student-teacher interviews, external evaluation, and anecdotal data show that First Year Design is well on its way to developing engineering communities of practice that include a more diverse lower-division student population. Though it has been difficult to track these student populations longitudinally due to COVID and significant changes to the Makerspace (COVID closures, relocation, and a 2023 relaunch), certain trends seem consistent and are a focus of an ongoing, more systematic analysis:

- Learners enrolled in First Year Design courses are more gender-balanced than the student population at our School of Engineering for both lower- and upper-division enrollments (36% female-identifying or nonbinary in First Year Design vs 20% in this School of Engineering).

- Significant percentages of learners who complete First Year Design go on to affiliate with engineering clubs (we estimate ~40%).
- Many lower-division students who complete First Year Design come back to take a different topic and/or propose and teach a future offering of a First Year Design course in the same or a new topic (at the time of writing, 85% of distinct student-teachers have been involved in at least two offerings of First Year Design, either initially as a learner or by teaching or coaching multiple courses – or both).
- First Year Design brings together students from different disciplinary foci (Figure 7).

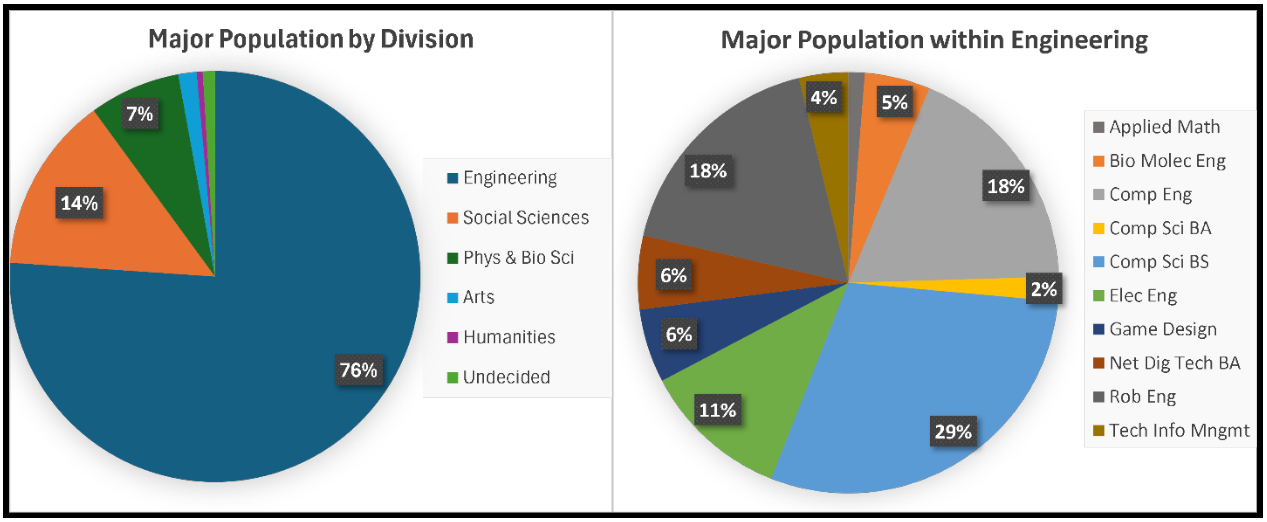

Figure 7: The distribution by majors for students enrolled in First Year Design since the 2019-2020 academic year. The left-hand graph depicts majors by university division, while the right-hand graph shows enrollments by major within Engineering.

We designed the exit survey instrument with the following goals in mind: to surface student learning and confidence in a set of engineering technical and professional skills; to evaluate the efficacy of different instructional features implemented across courses (including the teaching team); and to assess if the completion of a Design-Build class affects learners' decision-making capacity in declaring (or steering away from) an engineering major. We are currently undergoing an analysis of the anonymized data; the full results are not presented here and will be used to influence the next iteration of the instrument alongside assessments to be distributed throughout the quarter to intentionally surface ongoing identity work (e.g., reflection prompts, quiz questions, external evaluations with interviews). Note that survey data is accumulated at the end of the quarter, usually during the final session; it does not capture the perspectives of students who dropped the class earlier in the quarter. These learners commonly cite their need to focus on coursework for major requirements, suggesting better integration within department curricula is necessary. However, there have been instances where learners simply considered a class (Electronics) too "hard" or "time-consuming."

Based on the current data, learner feedback has been positive but does include suggestions for improvement. We use 5-point Likert items alongside open-response questions to capture how "helpful" individual course artifacts were in supporting learning and to gauge how "accessible" and "engaging" the course was as a whole. Except for the engineering notebook, 75% or more of responses were favorable, e.g., "helpful" or "very helpful" (4 or 5), for all Likert items (Figure

8). When analyzed chronologically, there is a general trend towards improvement, with more learners giving higher marks in recent course offerings.

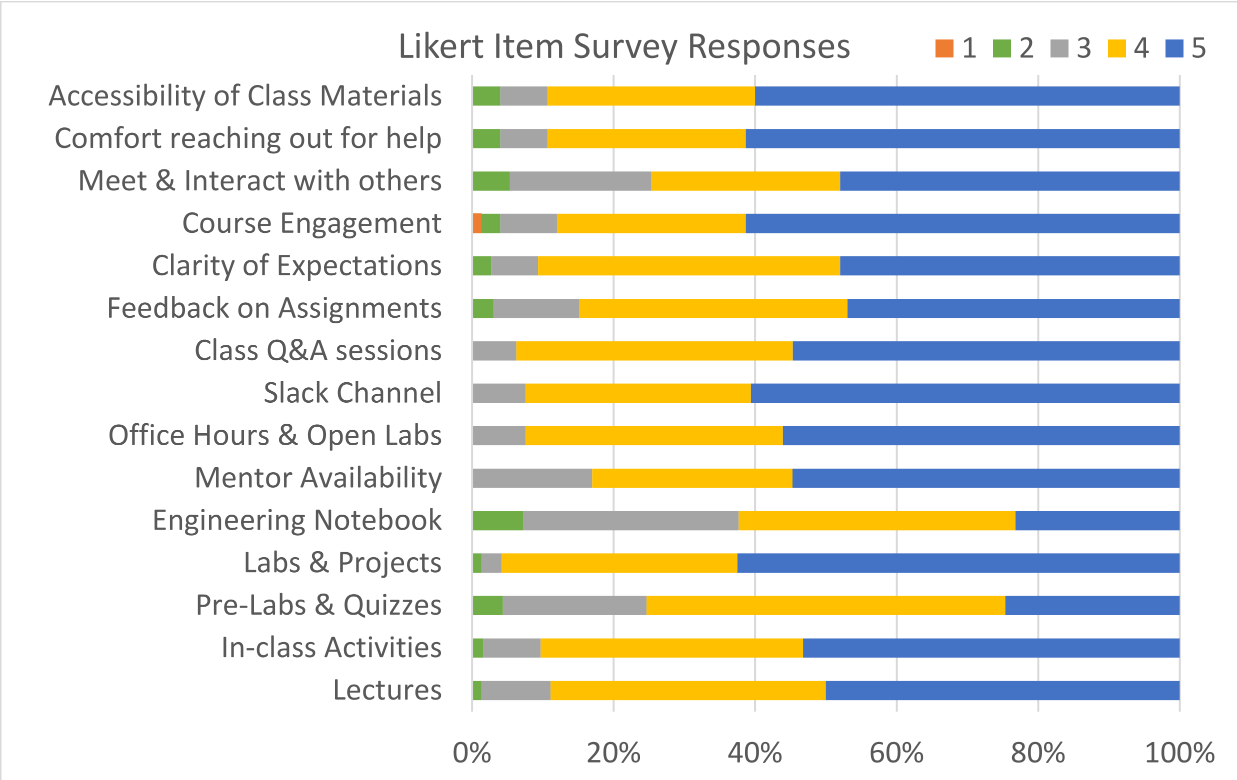

Figure 8: First Year Design survey participant responses for Likert items aggregated over Fall 2020 until Fall 2023. Prompts are abridged. Values 1 and 2 are unfavorable, 3 is neutral, and values 4 and 5 are considered favorable responses.

When asked in an open response question: "Which specific teaching practices, materials, and/or activities were particularly helpful for your learning and why?" we find the following themes emergent in a percentage of responses across courses:

- Active Learning through Projects (17%)
- Class organizational structure: prelabs to labs (10%)
- Accessibility of student-teachers (including via open lab hours and Slack) (25%)

When asked in an open response question: "How could this course be improved for future students?" there were fewer themes that applied across courses as responses seem to be class-specific (and thus context-specific). However, the engineering notebook is proving to be a polarizing artifact. As confirmed by the middling enthusiasm prevalent in this Likert item, open responses cite with nearly equal frequency that the engineering notebook is either beneficial, e.g., "conducive to learning," or frustrating. As one learner put it "[the notebook] was underutilized so that it didn't get a chance to shine." We speculate that the usefulness of this artifact must be carefully and authentically situated within the specific course topic for learners to fully embrace its use.

Challenges

The challenges of offering these First Year Design courses are typical of active and lab-based learning environments; they often take more administrative support, resources, and faculty time and do not easily scale. Smaller class sizes are better served by the teaching team of 2 or 3 student-teachers but have also proven to be a key factor in creating a true learning community. We found that when we limit enrollments but allow for a larger learner population through auditing, there is a much higher withdrawal rate across all learners than when we limit class size to 15 - 20 total enrolled students with no auditors.

Moreover, this program model pedagogically prioritizes student leadership and therefore adopts the additional challenges associated with student workloads and equity. Makerspace staff helps to administer the space and purchase, set up, and maintain equipment/parts. The topics offered routinely change based not only on the availability and external workload of student-teachers at any given time but also on their success in creating or updating a complete course; we cannot plan much in advance. We often only have a few weeks to prepare, placing a significant administrative burden on staff and associated faculty that TAs or student-workers cannot fill as they are not typically available between quarters.

As has proved to often be the case, the student-teachers themselves are the true experts in the course topic, such that disciplinary-specific TAs have been of limited help during teaching. First Year Design and Lead by Design welcome all learners and student ideas and thus are offered outside of engineering departments; we have yet to determine the best approach to secure efficacious TAs whose skills align with or complement those of the current student-teachers. This places more demands on the hired student-teachers during their teaching quarter– which may be a good thing if it offers needed financial support but may also compete with their degree-carrying workload. We identify this time burden of both First Year Design and Lead by Design as an equity issue. Past models paid student-teachers for course development over the summer. For scalability and accountability reasons, course development is now housed in the for-credit class Lead by Design during the academic year, limiting the student population who can afford to spend this time without pay. Note that student-teachers who successfully complete this class are then eligible to be hired to teach in subsequent quarter(s); they also have the option to come back to Lead by Design in a paid position as a Pedagogy Coach for prospective teaching teams. As our goal for next year is to better integrate equitable teaching practices into Lead by Design, our highest priority is to create a model that better exemplifies these practices.

Conclusions and Open Discussion:

Preliminary and anecdotal data show that our program model for First Year Design does provide a more welcoming and accessible learning environment for early engineering practice. The high-structure framework coupled with constructionist learning supportively brings engineering activities often found later in undergraduate engineering programs to lower-division learners while leaving room to navigate and embrace failure. Moreover, we postulate that this framework reduces the barrier for upper-division students to take agency over their learning environment and formally become role models, mentors, and teachers. Student-teachers are the key to making First Year Design welcoming and accessible to *more* learners. They inherently have the potential to create communities of practice that exceed the bounds of the classroom in ways faculty cannot. Thus, to move beyond welcoming to become truly inclusive and equitable, we must bolster our students' capacity to challenge the educational norms that entrench marginalization. Lead By Design is our venue for such training. Through the ongoing study of this program and by request of student-teachers, we prioritize the following areas for improvement, which we pose here as questions for the engineering education community:

- How do we better facilitate a space where all voices are heard and recognized as experts? We are concerned that the same voices repeatedly respond to questions and thus are regarded as experts, possibly detracting from others' engineering identity work. Are mixed-modality activity responses (e.g., discussion boards, polling) more supportive than open conversation?
- Are there benefits to utilizing a pass/no pass grading approach in first-year engineering programs? Can this be constructively tied to engineering identity with a "pass" equating to recognition as an engineer?
- How do we better scaffold accessible and equitable teamwork practices? By offering choice for the culminating project so that is relevant to the learner, the formation of learning groups is not randomized nor allows for out-of-class scheduling restrictions, leaving some team members with limited support from their team.

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