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# Getting to the Nuts and Bolts: Reclaiming Hands-on Learning in First-Year Mechanical Engineering

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## ABSTRACT

### BACKGROUND & CONTEXT

Many students enter engineering education without hands-on experience of the materials, tools and processes which they will be studying. Creating a curricular space in which all first-year students can have hands-on manufacturing experience poses significant space and time constraints.

### PURPOSE OR GOAL

This paper documents the development and implementation of a Workshop Practice course at a large South African university. Beginning with a pilot of 25 students in 2023, the course now offers 600 students a tangible foundation for integrating design theory with manufacturing practice.

### APPROACH OR METHODOLOGY

We adopt a case study methodology, using both Kolb's experiential learning theory and Vertically Integrated Project (VIP) lenses to analyse the design and delivery of the workshop experience. The intervention draws on the lead academic's long-standing integration of workshop practice, visual-spatial skills, and design thinking in VIP teams.

### OUTCOMES

Key features of the project which have contributed to its success are a student-centred approach, student ownership and growth through doing; space for creative expression and exploration; and vertical integration through the use of senior undergraduate students as teaching assistants.

### CONCLUSIONS

Basic workshop tasks offer students a real-world frame of reference for understanding dimensions, tolerances, and material properties – insights not easily achieved through lectures or CAD simulations alone. This exposure supports a deeper, embodied understanding of engineering design principles.

### KEYWORDS

Experiential learning; Vertically integrated project; hands-on learning.

## Introduction

> *The main purpose of it is the realization that less and less students arrive with practical experience. Students do computer work, or they do sports. Very few of them actually do something with their hands, and therefore they have very little exposure to typical engineering things. They don't play with engines and gearboxes like I did, for example. (Schalk)*

Across engineering education, digital simulation and theory-heavy curricula increasingly dominate early-year experiences, often at the cost of students' tactile engagement with real materials and components. At our large public university in South Africa, many first-year Mechanical Engineering students enter without ever having handled the "nuts and bolts" of design. This echoes the observations of Goff and Connor (2001), who note that many students have not "tinkered", and thus lack an experiential foundation to which engineering concepts and theories can be related.

In the last three years our department has rolled out a reimagined, in-house workshop experience rooted in experiential learning. This initiative was led by the third author, Schalk, who has two decades' experience in running a Vertically Integrated Project (VIP). Workshop Practice (WP) aims to connect students with materials, processes, and spatial reasoning early in their degree, offering a tangible foundation for integrating design theory with manufacturing practice.

Engineering programmes in South Africa are guided by the accreditation standards of the Engineering Council of South Africa (ECSA), a member of the International Engineering Alliance (IEA). The attributes which are expected to be in place when students graduate include professional competencies such as ethical judgement, teamwork, communication, independent learning, and sustainable engineering practice. At the University of Pretoria, engineering education is being redesigned to integrate professional and technical competencies, using a data-informed curriculum design approach and a participatory design process. As part of the larger transformation process to create an integrated, sustainability-oriented curriculum, the redesigned first-year Workshop Practice (WP) course aims to foster student engagement through lived, sensory encounters with tools, processes, and components that bring abstract concepts to life.

Kolb (1984) contends that deep learning requires students to move through all four stages of a learning cycle in which dialectic ways of grasping information (experiencing and thinking) and of transforming it into knowledge (acting and reflecting) are in creative tension. Morris (2020) extends Kolb's model, emphasising the balance between contextually rich concrete experience (incorporating place, time and embodiment) and abstract conceptualisation; and between pragmatic active experimentation (incorporating immersion in the unfamiliar) and critical reflective observation (testing concepts against experience).

Increased engagement with engineering, self-efficacy and confidence in engineering abilities are frequently reported as outcomes of hands-on experiential learning (Freuler et al., 2001; Taheri, Robbins & Maalej, 2020; Starkey et al., 2024; Yang & Chen, 2025). Dandu, Masson and de Leon (2007) report on a "footstone" project in the first year in which technical and professional skills are integrated, which gives a foundation on which to develop conceptual understanding. They note that although virtual experiences offer many affordances, particularly when scaling for large classes, tangible experiences in which the human senses are involved are important for learning and for motivation. Ssemakula (2002) also highlights the inherent motivation of creating a functional product. The growth of the Maker movement has created increasing opportunities for students to seek out hands-on experiences (Holloway & Oakes, 2017; Yang & Chen, 2025). However, space and time constraints frequently limit the extent to which hands-on manufacturing experiences are included in the formal curriculum (Knight, Carlson & Sullivan, 2003; Holloway & Oakes, 2017; Starkey et al., 2024).


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Vertically Integrated Projects (VIPs) offer a sustainable model for integrating experiential learning, research, and curriculum development in engineering education. These long-term, multidisciplinary team structures engage students across academic levels in authentic design and research challenges, often linked to industry or community contexts. At the University of Pretoria, VIP teams such as the long-standing TuksBaja project have provided a platform for students to build both technical and professional competencies in a scaffolded, team-based environment.

The VIP structure fosters collaboration between junior and senior students, enabling peer learning, continuity of knowledge, and a deeper engagement with design practice over time. Within a VIP, students do not take on the role of passive audience but are active participants in learning through helping each other to understand engineering concepts and are collaborative members of project teams (Pai et al., 1998). Students embark on the "kinds of active, critical and analytic enquiry undertaken by researchers" (Fung, 2017, p. 20), and have opportunities to be more experiential and self-motivated in their approach to learning (Strachan et al., 2019).

This paper documents and analyses the development of the Workshop Practice experience at the University of Pretoria. The paper contributes to the scholarship of teaching and learning (SoTL) by asking: *How do the design and implementation of a first-year workshop practice course align with experiential learning theory and vertical integration?*

## Methods

This practitioner-led SoTL study uses a qualitative case study approach to explore the design, implementation, and scaling of a hands-on workshop experience for first-year engineering students at the University of Pretoria. It forms part of a broader project focused on curriculum transformation and staff capacity-building across the School of Engineering.

### Positionality

We are three academics from the mechanical engineering department at a large public university in South Africa, who are all actively involved in curriculum reform efforts. The workshop practice project which is documented in this paper has been conceived, designed and implemented by the third author, Schalk, in collaboration with a team of workshop instructors and student Teaching Assistants (TA's). The first and second authors, Helen and Lelanie, are documenting this project as an innovative pedagogical approach to a practical problem experienced in our university. Helen brings a First Year Experience perspective to this paper. Lelanie and Schalk bring experience with vertically integrated project (VIP) teams that connect theoretical learning with practice.

## Data Collection

The first source of data was a semi-structured interview with Schalk, conducted by Lelanie, which was recorded and transcribed by an AI tool. The conversation lasted approximately 60 minutes and explored the educator's motivations, design intentions, constraints encountered, pedagogical values, and observations from the implementation. The interview questions, designed to elicit reflective insights related to our research questions, are reported in Table 1.

The second source of data was a conversation between Schalk and Helen, eliciting further details of the practical tasks which students complete during the workshop practice week. Helen took photographs of two different lamps which formed the basis of student projects and took notes capturing details of the manufacturing steps included in each design. The third source of data was a document giving the timetable and budget for the planned 2025 workshop. These multiple data sources were used to map the learning sequence, identify implicit pedagogical choices, and triangulate Schalk's reflections with observable evidence of implementation.

**Table 1: Interview questions**

| | |
|---|---|
| **Background and Motivation** | What made you feel that the previous workshop arrangement was not serving the students well?<br>What were your main goals when designing the in-house workshop experience for first-year students? |
| **Design Process and Decisions** | How did your experiences with the TuksBaja team influence the way you thought about the workshop content and activities?<br>What were some of the constraints you faced (e.g. time, tools, space, number of students), and how did these influence your decisions?<br>Were there any specific skills or ways of thinking you wanted students to develop through this experience, beyond just using tools?<br>Can you describe how you structured the workshop session — what students did first, next, and last?<br>Did you build in any moments for students to pause and reflect — or to connect what they did in the workshop with their other coursework? |
| **Observations and Reflections** | What stood out to you in how students responded to this experience — in terms of confidence, understanding, or engagement?<br>If you could redesign this experience again from scratch, what would you do differently, and why? |
| **Closing** | Why do you think hands-on experiences like this matter in modern engineering education, especially at first-year level? |

## Data Analysis

The data collected were read and analysed separately by Helen and Lelanie, to build a rich description of the Workshop Practice program, including its design, operation and guiding philosophies. We include direct quotes from Schalk when appropriate to give context.

We used Kolb's experiential learning theory to analyse how the structure and activities of WP aligned with the four elements of the learning cycle: concrete experience, reflective observation, abstract conceptualisation, and active experimentation. We further drew out elements of WP which align with the Vertically Integrated Projects framework.


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Our analysis combines practitioner-informed interpretation with critical reflection through the chosen theoretical lenses.

## Details of the Workshop Practice Course

First year engineering students in five departments at our university are required to attend a single-credit, weeklong workshop practice course (WP) during one of the university vacations. Before the intervention described in this paper, WP was outsourced to external contractors who had sufficient machining facilities to allow all students to complete basic manufacturing tasks including turning, machining, soldering and welding. This was costly in several ways, including the hiring of buses to transport students from campus to the external site, payment to the external contractor, and long days for students due to the time required for transportation. Further, informal feedback from students indicated that they would spend up to half a day waiting for the bus to bring them back after they had completed their tasks, reducing students' interest in and appreciation of the experience.

The Mechanical Engineering department decided to bring this workshop practice in-house, sacrificing some of the exposure to specialised manufacturing processes but compensating with a more coherent design which aligns with the rest of the first-year curriculum. This initiative introduces students in their first year to our in-house manufacturing capabilities, including workshops, laboratories and skilled instructional staff.

### Workshop Practice Overview

Students are assigned to attend one of several weeklong sessions scheduled during university holidays. Each weeklong session accommodates up to 70 students, who are further divided into three groups. The range of activities which are scheduled are listed in Table 2. There are general activities where all the students are in a formal lecture room environment for a short time. Most of the time is spent in the labs, doing individual activities on a rotational basis in their groups. These groups are small enough to receive dedicated attention from instructional staff and workshop TA's.

**Table 2. Activities during Workshop Practice Week**

| Lectures | Lab visits and technology demos | Practicals | Practicals |
|---|---|---|---|
| (50 min) | (50 min) | (50 min) | (2 to 4 hours) |
| Introduction<br>Health and Safety<br>Drawings<br>Tools [a]<br>Gears, Pulleys and Bearings<br>Fasteners [a] | Workshop<br>Vehicles lab<br>Thermodynamics lab<br>Experimental structures lab | Tapping<br>Measurement<br>Materials | Wiring and Electricals [b]<br>Welding [b, c]<br>Woodwork and plastic shaping [c]<br>Hand Tools [c]<br>Spray Paint [c]<br>Soldering [b]<br>Assembly [c] |
| [a] Includes in-class practical activity<br>[b] Includes pre-practical lecture<br>[c] Working on project component | | | |

The WP curriculum is designed to give students broad exposure to a wide range of activities and components, as well as deeper exposure on certain activities. It is not possible in a week to train students to operate a lathe or a milling machine, but it is possible to give students an experience of and feeling for a range of mechanical, electrical and electronic components. Every student does some activities individually (such as arc welding and soldering), some activities are group-based, and some simply create awareness.

The WP curriculum complements the formal curriculum of the first year, as illustrated in Figure 1. An example of the benefit of teaching students in the workshop environment is the Occupational Health and Safety lecture, which would be almost impossible to teach

authentically in a traditional academic setting. Because the students are about to go into a workshop it makes perfect sense, and therefore they recall that information well.

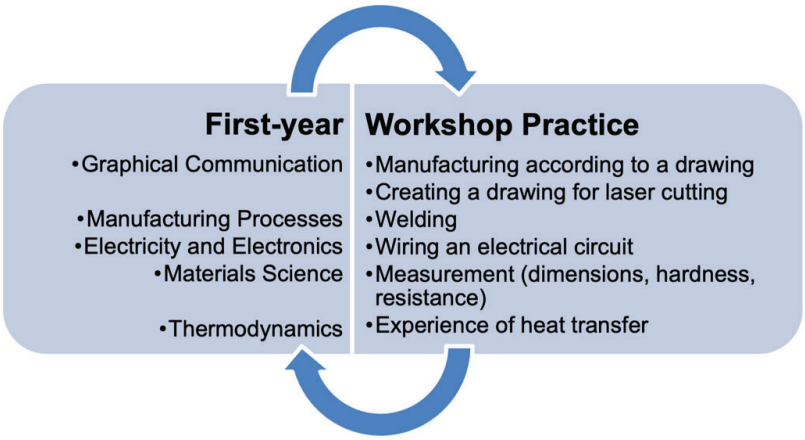



**Figure 1: Alignment of WP content with first year curriculum**

The practical activities have been designed to be scalable, carefully choosing readily available and inexpensive methods for providing active experiential learning. Some exemplars of the simplest practicals are listed here.

- **Toolbox:** A small group of students receives a toolbox as well as a list of the tools. The students match the tools to the list.
- **Fasteners:** Starting with a bin containing a range of old bolts and nuts, identify how many M10 by 50 mm Allen caps are in the bin, measuring using Verniers.
- **Electrical:** Wire together an electrical circuit, connecting a buzzer and an LED to a power source in a continuity test. Use a multimeter for investigations.
- **Materials:** A block of steel and a block of plastic come out of the fridge. They are both at the same temperature, but the steel feels colder than the plastic because of the difference in heat transfer properties.

Describing the materials practical, Schalk says,

> *There's no mathematics or thermodynamics, but you can feel the difference. You hold the two pieces of material in your hands, and you will probably never forget it, and that's the beauty of this kind of experience.*


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Several of the practicals contribute to the manufacture of a lamp, a useable and tangible reminder of what students have learned. Figure 2 shows the lamp which was manufactured by the 2024 cohort. Figure 3 is a prototype of the lamp manufactured by the 2025 cohort. The figures show the manufacturing tasks which are incorporated into the production of each lamp.

The 2025 lamp incorporates options for students to customise aspects of the geometry and colours of the design. The larger message in allowing self-expression is that design is expected to be creative, and students are allowed to be creative in their execution. Handing over ownership of the project builds enthusiasm. Students are more motivated by producing something which they will take home than by completing isolated manufacturing tasks. The

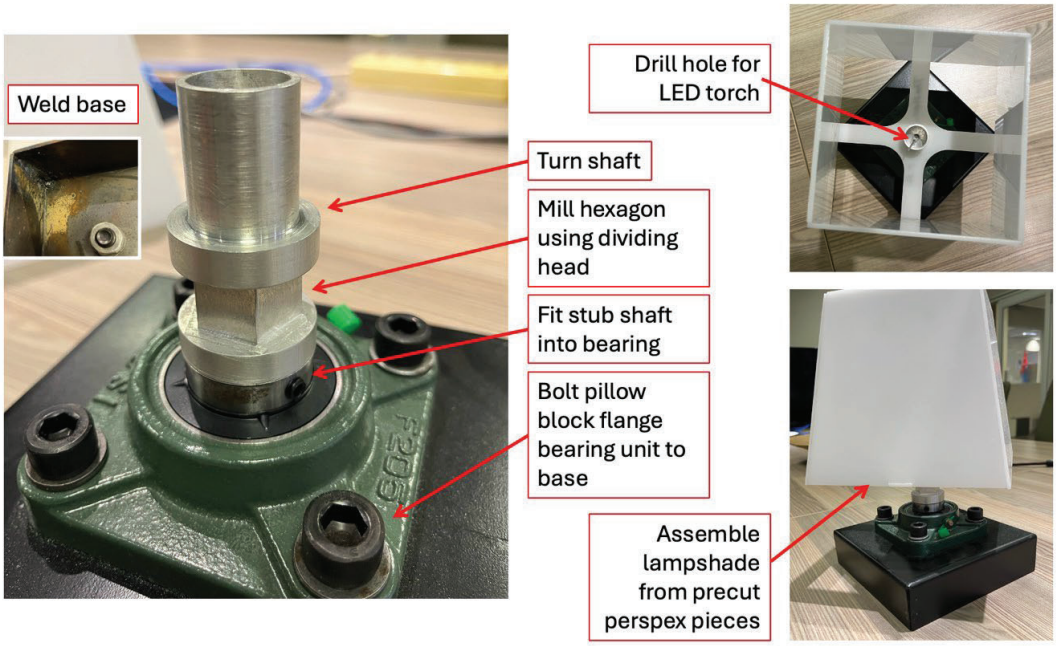



**Figure 2: Manufacturing tasks on lamp project for 2024 cohort**

finished product feels like an achievement, which students can show to friends and family with pride in what they have accomplished. Students may struggle to feel that they are making progress in an academic course. In contrast, if they do something with their hands, after a few hours they can see what they've done and show their progress to other people.

## Developing the WP Course

The WP course was developed over three years. A pilot project was run in 2023 with 25 volunteers from the first-year class. In 2024, the full mechanical engineering first-year class of approximately 250 students attended the in-house WP, and in 2025 this has been extended to include approximately 600 students from all five participating departments. Critically, the course has been developed and implemented by a distributed team, including technical staff, student TA's and peer mentors.

The pilot project in 2023 was used to establish what was feasible. The biggest risk initially was that it was difficult to know how long students would take to complete tasks, and hard to estimate the level of skills and experience which students would enter with. The first year took a lot of effort to design the course, and the second year, with five groups of students, still required thinking through logistics. After two years, the work is mainly in handling the larger numbers of students, but the thinking has been done. The team knows what works and what doesn't, and the uncertainty is now diminished.

Significant constraints in designing the WP course were space and equipment. A large vacated workshop space with ventilation was made available, and custom welding tables and screens

to put between the welding stations were manufactured and assembled by the workshop TA's. The workshop does not have enough fixed equipment – lathes and milling machines – to accommodate the student numbers. However welding machines, soldering irons and hand tools are relatively inexpensive, and could be bought for each workbench, allowing every student to complete their own project. By designing and resourcing the activities intelligently,

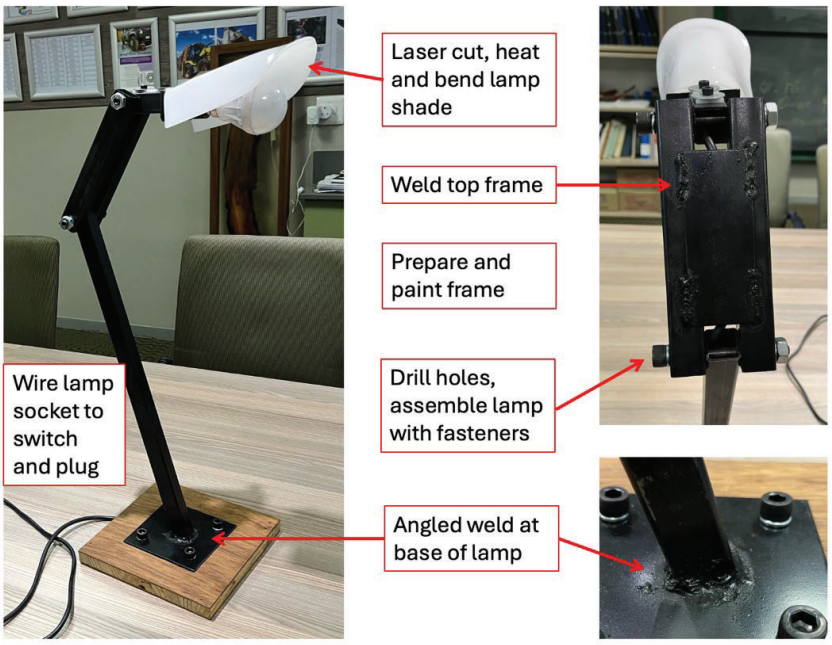



**Figure 3: Machining tasks on prototype lamp project for 2025 cohort**

it is possible to offer meaningful experiential learning without requiring a large amount of additional resources.

### Observations on Student Behaviour

In this study, we have not surveyed students directly, but observations of student behaviour give some insight into students' experiences of the WP course. A key observation is that students remain at the workshops and are busy until closing time, and some stay to ask questions after the end. Attendance is significantly higher than in normal lectures. The fact that students arrive on time and do not need to be micromanaged is evidence that they find the experience engaging and enjoyable. Many of the students who participated in the 2023 pilot have enrolled to be TA's in later years, and have contributed to the ongoing development of the course.

## Discussion

### Pedagogical Reasoning and Student-Centred Design

Schalk's core motivation for transitioning away from an external, off-campus workshop stemmed from student feedback and a desire to re-anchor learning in the university's own ecosystem. Giving students tangible experiences to develop their "feeling" for engineering is

> *not about welding, it's about looking at life differently; not going through the world with your eyes closed.*

His pedagogical intent was clear: give students a lived, embodied experience of engineering materials and processes, and do so in a way that is accessible, motivating, and contextually relevant.


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This philosophy reflects a commitment to *meeting students where they are* — offering scaffolding for those with no prior exposure, while enabling advanced learners to develop new competencies. For example, students already comfortable with arc welding were encouraged to explore TIG or MIG welding, rather than repeat familiar tasks. This approach of differentiated challenge echoes experiential learning's emphasis on learner ownership and growth through doing.

The intentional design of a take-home artefact — a functional lamp with elements of design freedom — served as both a motivational tool and a concrete symbol of accomplishment. As Schalk puts it, *"*You want to take this home and show it to your family. That changes everything."

## Experiential Learning in Action

Although Kolb's experiential learning theory was not used in designing and developing the WP course, many of the principles are reflected in the implementation:

- **Concrete Experience:** Students engage in tasks such as welding, measuring, or wiring, producing a tangible object (a lamp) they can take home.
- **Active Experimentation:** Those who choose to customize the lamp – by using CAD to cut a personalized shade or modifying design dimensions – move beyond replication into experimentation and design thinking.
- **Abstract Conceptualisation:** Students connect workshop experiences to lectures (e.g., on Occupational Health and Safety). Workshop experience is also connected to theoretical learning in the first-year curriculum.

Reflective observation is the one component of Kolb's model that is not explicitly present in Workshop Practice, although there is opportunity for informal reflection:

> *When everybody has their lamps, of course, they look at each other's. There is always discussion about, "Oh yeah, I like this", or "Look at my welding. My welding is really nice. Your welding, wow, you need to come back next week to do more welding."*

The course prepares students to receive theory differently, reversing the typical "theory first" approach. As Schalk noted, *"*It's much easier to understand fits and tolerances when you've actually tried to place a bolt in a hole." Including formal opportunities for reflection into WP is an opportunity for enhancement of the course in future.

## Vertical Integration

Workshop Practice is a clear example of the benefits of vertical integration for students and for staff. Many of the TA's, who participated in courses in 2023 and 2024, signed up this year because they appreciated the experience and wanted to help the next generation of students. The 2025 lamp design was the winning concept out of a number of different concepts developed by the TA's, and demonstrates that senior students are thinking about how they can help the junior students learn as much as possible. When students have an opportunity to be the teacher they take on a different position, and that makes them think about things in a different way.

Once momentum has been established with this kind of activity, it starts to run itself. The academic staff share responsibility with the students, who become co-teachers. This gives the students experience, and alleviates the burden on staff to do everything themselves.

In vertically integrated projects the goal is to motivate people to think out of the box, implement ideas and see what works and what doesn't. The team has the experience of being part of something bigger, not about what each person can achieve individually, but rather what can the team achieve together. Team members gain technical experience, as well as management

and teamwork experience, as part of a community. Schalk says, “We are kind of adventurous. This is high risk, high reward.”

## Conclusions and Implications

This case study offers practical and theoretical insights for rethinking the structure of early-year engineering curricula. In an increasingly digital world and in amongst many theoretical science and engineering courses, Workshop Practice offers first-year students time and space to play with the nuts and bolts of their chosen profession, and to create their own physical artefact.

Incorporating hands-on manufacturing experience into the first year of engineering study is not new. What is significant in this study is the pragmatic decisions which allow this experience to be scaled to accommodate more than 600 students. The design of this experience incorporates simple low-cost practicals, such as measuring and sorting bolts, which give students experience with measurement and allow them to feel the weight and size of components which they might otherwise only see in a textbook. Recognising the financial and space constraints of certain machining processes, Workshop Practice was designed to give students maximum opportunity to do machining themselves, focusing on welding and soldering. The staff who guide first-year students through the course include many undergraduate engineering student TA’s, sharing their passion and knowledge. The vertically integrated structure dramatically increases the long-term sustainability of this project.

This paper demonstrates the pedagogical value of anchoring learning in physical experiences, especially when guided by academics with strong industry and student development expertise. In an age of automation and abstraction, we argue for the enduring value of “making” as a critical dimension of engineering education.

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