From Bottles to Braille: What We Learned from a One-Semester Service Design Project

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From Bottles to Braille: What We Learned from a One-Semester Service Design Project

Abstract

We are five first-year mechanical engineering students and a faculty mentor who participated in a semester-long, socially responsive design project during Fall 2025 at the South Dakota School of Mines and Technology. In this paper, we use sistematización de experiencias, a participatory, reflexive methodology rooted in Latin American critical pedagogy, to reconstruct and interpret what we learned through the project and through the process of collective reflection itself. The experience emerged from a community request connected to plastic pollution on the island of Ometepe in Nicaragua. Our engineering task was to prototype a low-cost system that converts discarded PET bottles into 3D-printing filament, with the longer-term goal of enabling locally produced Braille labels and assistive tools for blind and deaf community members.

All members of our team are participants and co-authors. The student researchers co-led the formulation of the research questions, developed the focus group protocols, and participated directly in thematic analysis. The faculty mentor participated as a co-subject rather than an evaluator, contributing methodological expertise, technical communication, and dialogic reflections while intentionally adopting a coaching role. We acknowledge persistent asymmetries in experience and responsibility; rather than erasing them, this study makes them visible as part of the negotiation of meaning and authority.

Guided by two questions: (1) What did we learn technically, personally, and professionally through a one-semester, socially driven mechanical design project? and (2) How did we make sense of that learning through collective reconstruction? We drew on two semi-structured focus group interviews and design artifacts (e.g., prototypes, failed prints, filament samples, documentation). Findings show that learning was strongly shaped by conditions often treated as peripheral in early mechanical engineering coursework: access to a flexible workspace, repeated failure and rapid iteration, scope negotiation under real constraints, responsibility to a real client beyond grades, and trust-based mentorship that positioned students as capable decision-makers. By foregrounding reflection as a method and treating lived experience as a legitimate source of engineering knowledge, this paper contributes a situated account of how first-year students develop mechanical judgment, agency, and emerging professional identity through socially accountable making, and how faculty roles can evolve to support more horizontal, student-driven inquiry in engineering education.

Introduction

Mechanical engineering education has long relied on learning-by-making through machining, fabrication, instrumentation, prototyping, and iterative testing as a central pathway into professional competence. The epistemology of the discipline is materially grounded: mechanical judgment develops through engagement with physical systems, diagnosing failure, adjusting tolerances, and iterating under real constraints. National calls for reform in engineering education have emphasized experiential, design-centered, and socially responsive approaches that better reflect the realities of contemporary engineering practice [1], [2].

Despite these aspirations, first-year mechanical engineering experiences often remain highly structured and procedure-driven. Access to fabrication laboratories may involve restricted hours, layered approvals, and regulated workflows. While safety and quality control are essential, such institutional structures can unintentionally slow iteration and reduce opportunities for independent mechanical judgment. This creates a gap between how mechanical engineers learn in practice and how students are permitted to learn in early coursework.

Service-learning and community-engaged design initiatives offer an alternative model by situating engineering work within authentic social contexts. Rather than solving abstract textbook problems, students engage real clients and navigate sociotechnical constraints that extend beyond technical specifications [3]. These experiences can foreground responsibility, stakeholder awareness, and ethical consequence as integral components of engineering practice.

At the same time, first-year engineering education plays a critical role in shaping persistence, belonging, and professional identity formation. Early academic experiences significantly influence whether students come to see themselves as engineers and remain in the field [5]. Yet less is known about how socially accountable, fabrication-based projects in flexible learning environments contribute to identity development in mechanical engineering specifically.

This paper addresses these gaps by reconstructing a semester-long, socially driven mechanical design project undertaken by first-year mechanical engineering students and a faculty mentor. Using sistematización de experiencias (systematization of experiences) as a participatory and reflexive methodology, we ask:

1. What did we learn technically, personally, and professionally through this one-semester, socially driven design project?
2. How did we make sense of our shared experience through collective reflection and reconstruction?

By situating this experience within scholarship on experiential learning, human-centered design, institutional learning environments, and engineering identity, we contribute a situated account of how space, iteration, responsibility, and trust function as mechanisms of early mechanical engineering formation.

Literature Review

Over the past two decades, engineering education scholarship has increasingly emphasized experiential, project-based, and design-centered pedagogies. The National Academy of Engineering's The Engineer of 2020 called for engineers who are adaptable, ethically grounded, and capable of addressing complex societal challenges [2]. Similarly, Jamieson and Lohmann argued for systematic innovation in engineering education, emphasizing integrative and practice-oriented learning environments [1].

Inductive and active learning approaches have been widely advocated. Prince and Felder's review demonstrated that problem-based and active learning approaches improve conceptual understanding and student engagement relative to traditional lecture models [6]. Kolb's experiential learning theory provides a widely cited framework for understanding how concrete experience, reflective observation, conceptualization, and experimentation form a recursive learning cycle [7]. Iterative prototyping environments in mechanical engineering naturally instantiate this cycle.

Engineering design has been recognized as central to professional formation. Dym et al. argued that engineering design thinking involves managing ambiguity, generating alternatives, and making informed trade-offs under constraints [8]. Sheppard et al. emphasized that engineering education must integrate technical analysis with design, professional skills, and contextual awareness [9]. Within this reform landscape, first-year design experiences have become increasingly essential entry points into authentic engineering practice.

Learning-by-Making, Makerspaces, and Institutional Constraints

The growth of academic makerspaces reflects broader efforts to support hands-on, student-centered learning. Wilczynski described academic makerspaces as environments that foster rapid prototyping, creativity, and interdisciplinary collaboration [10]. Blikstein argued that digital fabrication environments enable constructionist learning by allowing students to design and build meaningful artifacts [11].

However, institutional integration of fabrication spaces introduces tensions. Forest et al. noted that while makerspaces aim to promote innovation, institutional policies around safety, equipment access, and resource management can constrain experimentation and slow iteration [12]. In early mechanical engineering coursework, these constraints shape students' perceptions of hands-on learning. Rather than experiencing iteration as exploration, students may encounter fabrication as a regulated procedure. This tension between rapid iteration valued in professional practice and the controlled pace of institutional labs remains underexplored in mechanical engineering education research.

Service-Learning, Human-Centered Engineering, and Identity Formation

Service-learning integrates technical development with social responsibility by situating engineering work within authentic societal contexts. Community-engaged engineering projects have been shown to enhance motivation, contextual understanding, and professional responsibility [3]. Human-centered design further frames engineering as addressing “wicked problems” embedded within complex human systems rather than isolated technical artifacts [13]. Similarly, Sen’s capability approach positions technological value in terms of expanding human freedoms and opportunities [14]. Together, these perspectives conceptualize engineering as socially embedded action rather than technical optimization alone.

Such framing may be especially consequential in the first year, when students are forming early understandings of engineering and their place within it. Research on persistence shows that students often leave STEM due to disconnection rather than lack of ability [5], and Tinto emphasizes the importance of academic and social integration in shaping continuation decisions [15]. Engineering identity scholarship similarly demonstrates that identity develops through participation in authentic disciplinary practice and recognition as competent contributors [4],

[16]. Early engagement in meaningful, practice-oriented experiences has been shown to influence engineering trajectories [17]. Existing research on service-learning, human-centered design, and engineering identity broadly addresses these topics in parallel. What remains underexplored is how these dimensions converge in fabrication-based first-year mechanical engineering experiences and how that convergence influences students' emerging professional commitments.

Methodology

This study employs *sistematización de experiencias*, a participatory and reflexive methodology rooted in Latin American critical pedagogy, to retrospectively examine a semester-long service-learning design project carried out by first-year mechanical engineering students and a faculty mentor. Sistematización positions lived experience as a legitimate source of knowledge and emphasizes dialogic reconstruction, collective interpretation, and critical meaning-making rather than external evaluation [18], [19].

Rather than focusing primarily on developing a system to convert post-consumer PET bottles into 3D-printing filament for producing Braille labels in Nicaragua, we center the learning process itself, examining what we came to understand technically, personally, and professionally through sustained engagement with a real client. In this framing, reflection is not a post hoc requirement but a methodological lens through which meaning is generated, negotiated, and articulated, consistent with dialogic and participatory research traditions in education [20], [21], [22], [23].

Within this process, we as first-year students acted as methodological decision-makers, leading the formulation of research questions, co-developing interview protocols, and participating directly in thematic analysis. The faculty mentor served as a co-subject, contributing to engineering education research while intentionally adopting a coaching rather than an evaluative role. This structure aligns with horizontal research approaches that challenge extractive models of inquiry and redistribute epistemic authority [20], [21].

The Experience Under Study

We carried out this project as an optional, course-affiliated design opportunity stemming from ME110 – Introduction to Mechanical Engineering, structured as a ten-week Project-Based Learning experience. Our task was to design, assemble, and test a functional filament extruder capable of converting discarded PET water bottles into usable 3D-printing filament. The project foregrounded sustainability, hands-on manufacturing, teamwork, and engineering problem-solving under real-time and material constraints.

The project originated from a community request, which meant we were working for a real client rather than completing a simulated classroom exercise. This shifted our sense of accountability beyond grades. Decisions about materials, tolerances, assembly, and timelines had consequences for whether the system would actually work for someone else.

Instead of starting from a blank slate, the client informed us of an open-source project on GitHub called Polyformer (https://github.com/Reiten966/Polyformer/tree/main/.github) that includes all applicable CAD models and instructions for building the device. While this reduced initial design work, it introduced significant challenges. Much of the documentation was outdated or incomplete, several printed parts did not match the instructions, and key assembly steps, especially for the gearbox, were unclear. As a result, much of our work involved interpreting design intent, testing assumptions through trial and error, reprinting parts, and making minor but consequential adjustments to tolerances and alignment.

We divided and re-divided tasks related to 3D printing, mechanical assembly, documentation, and troubleshooting as the project evolved. Print failures, long fabrication times, and unexpected mechanical issues repeatedly disrupted our plans, forcing us to adapt our workflow and expectations. Over time, we came to understand the extruder not as a single machine, but as part of a broader manufacturing process that included preprocessing tools, assembly sequences, and operational testing.

The project concluded with a formal group presentation in which we presented the filament extruder, our design and assembly process, and the final results. We worked together to condense a large amount of technical information into a clear, organized format that would be easy to communicate to our peers. Preparing the presentation required us to reflect on what we learned and determine how to transfer that learning effectively to others. Presenting as a large group helped us practice public speaking, manage nervousness, and coordinate our communication on a complex, collaborative project.

Positionality

We are the same individuals who participated in the design project examined in this paper: a group of first-year mechanical engineering students and a faculty mentor. As students, we entered the project with varied and often limited experience in areas such as additive manufacturing, CAD, programming, and project planning. Our roles shifted throughout the semester as challenges emerged and as we learned from one another. These experiences, including uncertainty, frustration, and moments of accomplishment, inform the perspectives presented here.

Within the student team, we distributed responsibilities across several functional areas. Drew primarily contributed to manufacturing and printing tasks. Carsten focused on printing and educating other team members. Jager participated across all roles, supporting manufacturing, printing, education, and related functions as needed. Chase's role centered on manufacturing activities, while Ben contributed mainly to back-end work, including documentation and related organizational tasks. Two other students were part of the project but were not part of this reflection.

Dr. Vargas served as the faculty mentor and participated as a co-subject rather than an evaluator, intentionally adopting a coaching-oriented role that emphasized trust, transparency, and student autonomy. Writing this paper together became an extension of the learning process itself. Rather than attempting to remove our subjectivity, we engaged in collective reflection to make explicit how our positions and relationships shaped interpretation and meaning-making.

Figure 1. Informal photograph of the full research group involved in this project.

Data Collection

Data collection was designed to support the collective reconstruction and interpretation of our shared experience. We focused on creating structured opportunities for dialogue that would surface learning, tensions, and shifts in understanding as a group. To this end, our primary data sources were two semi-structured focus group interviews, complemented by ongoing project meetings and design artifacts produced throughout the semester. This study was considered as a No Human Subjects Research according to the IRB-2025-224 from the South Dakota School of Mines and Technology IRB office.

<u>Focus Group Interviews</u>

We conducted two focus group interviews shortly after completing the filament extruder. Both sessions included all project participants and were held via Zoom, recorded, and later transcribed. We intentionally chose focus groups because they allowed us to build meaning collectively, respond to one another's accounts, and negotiate shared interpretations of the experience in real time.

We designed the first focus group to broadly reconstruct the project and surface initial learning across technical, personal, and professional domains. The guiding questions were intentionally open-ended and reflective, including:

- What did each of us learn through this project—technically, personally, and professionally?
- What technical skills or knowledge did we develop, and where did we feel unprepared?
- Why did we decide to join this project in the first place?
- What does 3D printing mean to us after completing this project?
- What went wrong during the project, and what did we learn from those moments?
- How did we experience the project process step by step?
- What roles did we see ourselves playing, and how did those roles change?
- Would we want the university to support more spaces like this one, and why?

The second focus group was designed as a deeper, more focused inquiry informed by the first discussion. Building on emergent themes, we refined the protocol to probe specific tensions, decisions, and shifts in perspective. Guiding questions included:

- How did the necessary change of project scope—from an ambitious "Version 2.0" to completing "Version 1.0"—affect motivation and satisfaction?
- Did working on a service-learning project change how we view the role of mechanical engineers in addressing environmental or social issues?
- Several of us mentioned that trust developed quickly within the team. How did mutual trust between students and mentor shape our learning and sense of agency?
- How do we understand the trade-offs between the fast, hands-on learning enabled by a flexible project space and the slower, more controlled learning typical of institutional labs?
- How did learning CAD and 3D printing through hands-on work compare to learning these skills in more traditional classroom settings?

While the protocol was semi-structured, the discussion remained flexible. Participants frequently asked follow-up questions, built on each other's responses, and revisited earlier moments in the project, allowing new insights to emerge organically.

Design Artifacts

In addition to focus group data, we collected and examined artifacts generated during the design process. These included photographs of the extruder and team, videos documenting system operation, the completed and operational filament extruder, filament samples, and 3D-printed test cubes. We also reviewed supporting materials, including CAD files, GitHub repositories, and documentation videos. These artifacts served as prompts during reflection and as material traces of learning, collaboration, and problem-solving.

Data collection occurred across the whole semester. Design work, reflection, and dialogue were tightly intertwined. All participants provided informed consent and agreed to shared authorship of the experience. Given the small number of participants, our goal was not generalization, but a rich, situated understanding of how learning unfolded within this specific project context.

Data Analysis

Data analysis followed an iterative thematic analysis process grounded in sistematización de experiencias and supported by NotebookLM (Google) as an analytic aid. The analytic goal was not automation or theory generation, but collective sense-making through systematic organization, pattern identification, and iterative refinement of meaning. Our approach aligns with reflexive thematic analysis, in which themes are actively constructed through engagement with the data rather than discovered as objective entities [24].

We selected NotebookLM because it operates exclusively on user-provided documents and does not generate content beyond the supplied corpus. This constraint was essential for maintaining fidelity to participants' voices and minimizing the risk of hallucinations or fabricated evidence, as documented in generative language models [25].

NotebookLM functioned as an analytic support tool, assisting with organizing transcripts, surfacing recurring language, and supporting question generation. Interpretive authority remained with us as participants throughout the process, consistent with participatory and reflexive qualitative research traditions [22], [23], [26].

Round 1: Initial Thematic Mapping

In the first stage, we conducted an exploratory round of thematic coding using the transcript from Focus Group One and the accepted conference abstract. We prompted NotebookLM to identify recurring topics and experiences discussed during the session and to generate follow-up questions that could support deeper inquiry in a subsequent focus group. This round was intentionally open-ended and inductive, consistent with early-stage thematic mapping practices [24]. The full prompt used in this stage is provided in Appendix A. The resulting themes and questions were reviewed collectively. We discussed which patterns resonated with our experience, which felt overstated or misaligned, and which required further exploration. This discussion directly informed the design of the second focus group protocol.

Round 2: Thematic Refinement and Consolidation

In the second stage, we provided NotebookLM with the transcript from Focus Group Two along with prior analytic outputs. The prompt asked the system to identify themes that cut across both discussions, attend to shifts over time, and highlight tensions or contradictions. This stage aligns with the phase of theme refinement and consolidation described in reflexive thematic analysis, where candidate themes are reviewed, compared, and reorganized [24]. The full prompt used for this stage is included in Appendix B.

Round 3: Integrated Thematic Synthesis

In the final stage, we prompted NotebookLM to generate an integrated thematic summary drawing on all available materials, including transcripts, interview protocols, and selected project artifacts. This synthesis was treated as a provocation for discussion. We read the output aloud as a group and explicitly evaluated whether each theme accurately represented our shared experience. Themes that did not achieve a collective agreement were revised or removed. This process functioned as a form of participant validation, a recognized strategy for establishing trustworthiness in qualitative research [26]. The prompt used in this stage is provided in Appendix C.

Findings

In this section, we present the main themes that emerged from our collective analysis of reflections, group discussions, and dialogic writing. Rather than separating outcomes from process, we describe how learning unfolded through our shared experience. Writing in the first person reflects the epistemological stance of *sistematización de experiencias*: knowledge is reconstructed from within practice rather than extracted from it.

Theme 1: Learning Through Space, Failure, and Iteration

One of our strongest shared realizations was how deeply the learning space shaped what we learned and how we learned it. Working in a flexible, unsupervised environment gave us room to experiment, improvise, and fail without fear of penalty. We repeatedly contrasted this space with institutional maker spaces, which many of us experienced as restrictive and incompatible with iterative design work. As Drew put it during reflection: “Here, it’s like the open ocean, and the lab [Aquarium] is like being in a fish tank that’s too small, and you die in a month.”

This freedom also meant exposure to failure. Prints failed, parts didn’t fit, instructions were outdated, and components failed unexpectedly. Rather than seeing these moments as setbacks, we gradually came to understand them as necessary conditions for learning. Chase reflected on this shift in mindset: “I think what I learned for this is kind of plan for the failure, because we didn’t really plan out that the prints would fail.”

Through repeated cycles of trial, breakdown, and adjustment, we developed confidence not only in technical tools but in our ability to respond to uncertainty. Drew captured this collective realization when he noted: “The world’s gonna fight back against us reshaping it, and we need to be able to adapt to that.”

Our analysis of this theme was grounded not only in dialogue but also in shared examination of project artifacts. As shown in Figure 2, failed prints, partially assembled subsystems, and in-progress prototypes became focal points during collective reflection, helping us reconstruct how learning unfolded through material breakdown, iteration, and repair.

From the mentor’s perspective, allowing failure to unfold was intentional. Dr. Vargas reflected that the project was designed to surface difficulty rather than hide it: “The goal of this one was more about sustainability […] showing that making change is not easy either. It’s actually more complicated.”

Figure 2. Picture taken during subsystem assembly that was used for collective reflection

Theme 2: Negotiating Ambition, Scope, and Responsibility

At the beginning of the project, many of us were highly ambitious. We envisioned building multiple iterations of the machine and expanding its functionality well beyond what was realistically possible within a semester. Looking back, we recognized how disconnected these early plans were from the constraints of time, coursework, and material resources. Ben described this phase candidly: "All of us were too wide-eyed and bushy-tailed about our time… we were gonna make a whole second version."

As the project progressed, we were forced to confront these limits and reduce our scope. While this initially felt discouraging, it ultimately helped us understand what it means to plan responsibly as engineers. Drew reflected: "Once you start a project, you understand the reality of how much work it's going to take, so it felt a lot more in reach to finish our scope once we shrank it down."

What sustained our motivation was not grades or external pressure, but a sense of responsibility toward the client. Even when Dr. Vargas explicitly told us that it was acceptable not to finish, many of us felt a strong internal obligation to follow through. Carsten expressed this sentiment clearly: "We told [client], hey, we're gonna get you at least one of these… now we have to follow through with this." This sense of responsibility marked a shift from student compliance to professional commitment.

Theme 3: Human-Centered Engineering as a Lived Practice

Working with a real client fundamentally changed how we understood engineering. We could no longer think of our design as something that existed in isolation; it had to work for real people, in authentic contexts, with real constraints. Ben described this shift in perspective as transformative: “This project and our interaction with [client] made us more human-centered engineers… our creations are not going to be used in a vacuum.”

Our interactions with the client were not one-directional. Instead, they involved ongoing dialogue, negotiation, and translation of ideas into physical form. Drew reflected on this collaborative dynamic: “It was more of finding, ‘Hey, I saw this really cool thing, can we make it a reality?’ and trying to transfer those ideas into something physical.” These exchanges required us to consider usability, durability, and feasibility alongside technical performance.

Our analysis of this theme was grounded in a shared examination of material outcomes produced during the project. As shown in Figures 3 and 4, the operational filament extruder, filament samples, and 3D-printed test objects served as concrete reference points during reflection, helping us connect design decisions to use, context, and consequence rather than treating them as abstract requirements.

At the same time, we were aware that the project’s material impact was limited in scale. Rather than discouraging us, this realization helped us understand engineering as incremental and relational work. Carsten reflected: “This project itself has minimal impact… but it’s a good place to start… we’ve already started something that’s helping other people.”

For Dr. Vargas , this realization was an explicit pedagogical goal: “My hidden curriculum was to show that social change is complicated, and that engineering solutions are never as clean as we imagine.”

Theme 4: Trust, Mentorship, and Identity Formation

Trust emerged as a central condition shaping our learning and sense of identity. Rather than micromanaging, our mentor intentionally created space for us to struggle, decide, and lead. Many of us described his role using metaphors of coaching rather than instruction. Jager explained: “You were kind of the coach of this project… You gave us the game plan, but it was our job to figure out how to do that. [...] I think for me, I mean, this university as a whole is very well known for having good professors, good staff, as well as having very brilliant people who come out of this university, so I feel like for me, the trust with you came from the fact that you just work at a really good university. And then, when I got to know you as a professor, as well as, like, in class, but then with this project, like, when we, when Carsten, Ben, you [Dr. Vargas], and I, started talking about doing the research paper, and you had that, like, what was it, like, a half-hour, hour lesson?”

Being trusted to make decisions contributed to feeling treated as capable adults rather than novices. Carsten reflected on how this shifted his engagement: “The thing about growing up is how many of you get really upset when someone treats you like you’re four… letting me have that freedom to figure it out mattered.”

Figure 3. Operational filament extruder

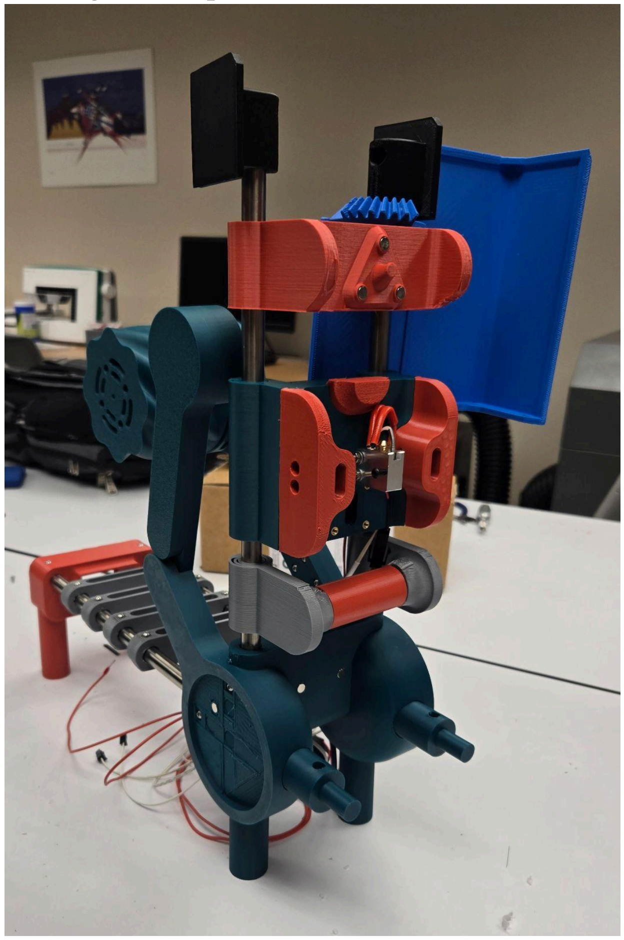
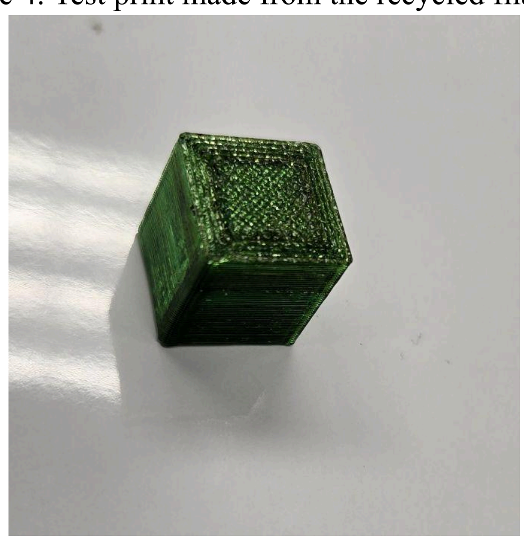


Figure 4. Test print made from the recycled filament



Trust also extended to technical expertise. Ben recalled a moment that made this explicit: "You asked me which printer to buy, and then you just ordered it. That showed me you trusted what I knew."

Through peer teaching, shared struggle, and collective problem-solving, we began to see ourselves and each other as engineers in practice. Chase summarized this shift: "I feel like ten times more confident that I can actually do it — approach a problem, work as a team, and figure things out."

Discussion

In this *sistematización de experiencias*, we set out to describe what happened during our project and collectively understand how the process shaped us technically, personally, and professionally. We aimed to trace learning not only as an outcome, but to reconstruct it as a process through which knowledge, identity, and responsibility were co-developed. As Jara Holliday emphasizes, *sistematización* is more than documenting events; it is a critical and dialogic reconstruction that gives meaning to lived practice, especially in educational and social contexts [18].

In keeping with these principles, this discussion reflects a collaborative synthesis of our shared learning. The ideas and thematic insights were developed through two rounds of collective reflection and writing. The faculty mentor led the theoretical framing, use of scholarly literature, and citation work in dialogue with the student authors. This guidance allowed us to retain our voices and experiences while also connecting to broader conversations in engineering education research. The faculty mentor joined the reflection process not as an evaluator, but as a co-subject. Asymmetries of power and experience were real but not hidden; instead, we acknowledged and negotiated them throughout the project. This position reflects Jara Holliday's view of sistematización as a horizontal, participatory method that values all forms of knowledge [18], and it challenges conventional models of research in engineering education, where students are often positioned as data sources and faculty as distant analysts [4].

1. Space, Failure, and Experiential Learning

One of the strongest realizations we had during this project was how much the physical and cultural space shaped our learning. Working in a flexible, unsupervised lab gave us the freedom to take initiative, iterate rapidly, and problem-solve in real time. We often compared this space to the "open ocean," in contrast to the "fish tank" of university labs, where bureaucracy, access restrictions, and safety protocols slowed prototyping. This freedom also meant risk exposure. We encountered broken prints, outdated instructions, and mismatched parts, but we came to see those failures as essential learning moments.

This insight aligns with Kolb's experiential learning theory, which argues that learning emerges from a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation [7]. Our learning was iterative and adaptive; it didn't happen through lectures but through trying, failing, and reflecting together. These moments of "productive struggle" were what built our confidence in CAD and 3D printing, as well as in how we approached and framed problems. For our mentor, it was also a learning experience: letting go of control and watching us navigate failure helped shift his view of first-year students' capacity for autonomy. He learned that with the right environment and trust, students could take on more leadership than is typically expected in engineering education.

2. Human-Centered Design and Engineering Purpose

This experience resonated with Buchanan's model of human-centered design, which centers empathy and human needs in problem-solving [13]. It also echoes Sen's capability approach in development theory, which emphasizes that the value of an action lies in how it expands people's freedom and ability to act in the world [14]. Although the global environmental impact of our project may be modest, the process changed how we see our role as engineers. It introduced sustainability as an embedded responsibility. For our mentor, witnessing this shift was a reminder of the emotional and moral dimensions of engineering that can be missed in technical coursework.

Designing a machine for a real-world client, specifically for blind and deaf users in Nicaragua, pushed us to think beyond technical performance. We had to consider materials, usability, and sustainability in concrete, contextual ways. These constraints shifted how we understood engineering: not just as building things, but as building for someone, with ethical and social dimensions.

3. Trust, Mentorship, and Shared Authority

Another core insight was the way mentorship and power operated in our group. Our mentor intentionally chose not to micromanage, even when the project's technical direction was unclear. We called this a "comfortable amount of struggle" that was hard, but never unsupported. This balance reflects Vygotsky's zone of proximal development, which describes how learning occurs best when scaffolding meets learners just beyond their current capabilities [27]. From the mentor's perspective, this also required constant reflection. Supporting without controlling meant learning to listen, knowing when to intervene, and resisting the impulse to correct. He had to trust that the experience itself, successes and failures, was pedagogically sufficient. Participating as a co-subject rather than a distant evaluator allowed him to remember how mentorship is not just about teaching, but about facilitating spaces of agency, as Ben mentioned: "[Dr. Vargas] Let us fail to a point[...] the comfortable amount of struggle keeps us motivated to solve the problem. And I feel like allowing us to struggle, but not letting us drown."

4. Identity Formation Through Practice

Through this project, we began to see ourselves as engineers in training. This shift was not symbolic; it was real. Having to deliver something meaningful to a real client gave us a level of ownership, accountability, and pride that grades alone couldn't provide. This insight aligns with research on engineering identity, which shows that meaningful participation in authentic practice is central to students seeing themselves as engineers [16].

This realization was also true for our mentor. While he brought experience in engineering education research, this project challenged him to reflect on how to create spaces where students can act as capable professionals. The process of writing this paper, watching and guiding us to lead the research, draft sections, and articulating insights, reinforced the idea that when students are trusted with real responsibility, they rise to meet it.

Conclusion

This *sistematización de experiencias* allowed us to critically revisit a project that shaped us in ways far beyond our initial expectations. By engaging with a socially meaningful design challenge early in our academic careers, we experienced firsthand how real-world engineering can spark learning in technical tools such as CAD, 3D printing, and project management, as well as in less visible dimensions such as ethical responsibility, collective identity, and persistence. The process of reconstructing this experience together helped us name and make sense of the knowledge we built as something we constructed through doing, struggling, and reflecting.

We came to understand that learning is neither neat nor linear. It is iterative, emotional, and sometimes uncertain. Much of what we gained emerged not from success but from difficulty, like failed prints, unclear instructions, scope creep, and time pressure. These were not failures to avoid, but rather conditions in which we learned to think critically, act creatively, and support one another. As students, we grew more confident because we were trusted to lead, even when we were unsure. Our mentor, participating as a co-subject in this process, deepened his understanding of how stepping back but without stepping away can open space for student agency and authentic growth.

Just as important as the technical work was the reflective process. Through dialogic reflection and collaborative writing, we could articulate how our perspectives shifted, how our identities as engineers began to take shape, and how our understanding of impact matured. In essence, this project became a shared inquiry into what it means to learn, to teach, and to act ethically in an uncertain world. Reflection here was not an add-on, but a generative part of how learning became visible.

Ultimately, we also confronted the complexity of social change. Creating a tool that turns plastic waste into Braille-accessible material was neither clean nor complete. It required constant adaptation and reminded us that impact cannot always be measured by efficiency or output. What matters is our commitment to keep trying, to stay with the problem, and to understand engineering as a relational, human practice.

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Appendix A

Prompt Used for Thematic Analysis – Round 1 (Exploratory Coding)

Context provided to the system

We are a group of first-year undergraduate mechanical engineering students at the South Dakota School of Mines and Technology, along with one faculty mentor. We participated together in a qualitative research project using *sistematización de experiencias* to analyze a semester-long, socially driven 3D-printing project focused on producing filament from PET plastic bottles.
We are working from an abstract accepted to an ASEE conference and a transcript from our first focus group interview.

Prompt

- You will conduct the first round of thematic analysis for a study on sistematización de experiencias.
- Your task is to identify recurring topics, patterns, and themes discussed during the focus group that relate to learning, motivation, challenges, failure, mentorship, teamwork, space, and identity.
- In addition to identifying themes, generate follow-up questions for a second focus group to deepen our understanding of the experience and push the analysis beyond surface-level description.
- Work only with the provided materials. Do not invent information or introduce concepts that are not grounded in the transcript or abstract.
- If clarification is needed, ask questions before proceeding. Take your time to be thorough and accurate.

Purpose of this prompt

This prompt was designed to support exploratory thematic mapping and to inform the design of the second focus group interview. Outputs were treated as provisional and reviewed collectively.

Appendix B

Prompt Used for Thematic Analysis – Round 2 (Thematic Refinement)

Context provided to the system

We are continuing a sistematización de experiencias study with the same group of participants. We now provide the transcript from the second focus group interview, along with the accepted abstract and preliminary themes generated in Round 1.

Prompt

- You will conduct the second round of thematic analysis for this project.
- Your task is to identify themes that appear across both focus group discussions and to refine, consolidate, or reorganize them where appropriate.
- Pay particular attention to:
  - Shifts over time (e.g., changes in motivation or understanding)
  - Tensions or contradictions in participants' reflections
  - Connections between technical learning, identity formation, and mentorship
- Work strictly within the provided data. Do not generate new themes that are not supported by participant language.
- If clarification is needed, ask before proceeding. Take your time to be careful and accurate.

Purpose of this prompt

This prompt supported analytic consolidation across both focus groups and helped identify stable themes that would later be evaluated through collective discussion.

Appendix C

Prompt Used for Integrated Thematic Synthesis

Context provided to the system

We are finalizing the thematic analysis for a sistematización de experiencias study. The materials provided include:

- The accepted conference abstract
- Focus Group One transcript
- Focus Group Two transcript
- Interview protocols for both focus groups
- Preliminary thematic analyses from Rounds 1 and 2
- Selected project artifacts (documentation descriptions)

Prompt

- Create a coherent and well-structured thematic analysis summary that integrates findings from both rounds of analysis.
- Your task is to identify overarching themes that address our research questions about learning, struggle, trust, space, responsibility, and identity development.
- The output should be organized, descriptive, and grounded in participant language.
- This summary will be used as a starting point for collective discussion, not as a final analytic product.
- Do not invent data, interpretations, or conclusions beyond what is supported by the provided materials.

Purpose of this prompt

This prompt supported analytic coherence and helped ensure alignment across themes. The output was read aloud and evaluated collectively; themes lacking group agreement were revised or removed.