2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #52502

# Measuring Sustainability Mindsets in University Makerspaces: Design and Initial Validation of the Material Availability Policy (MAP) Survey Instrument

**Dr. Nelson A. Granda Marulanda, North Carolina Agricultural and Technical State University**

Nelson A. Granda Marulanda, Ph.D. is an Assistant Professor in the Applied Engineering Technology department at North Carolina A&T State University. He holds a B.S. in Electrical Engineering from the University of Puerto Rico at Mayaguez, an M.S. in Manufacturing Engineering from the Polytechnic University of Puerto Rico, and a Ph.D. in Industrial and Systems Engineering from The University of Tennessee, Knoxville. Dr. Granda's research and teaching are rooted in Sustainable Development through the Triple Bottom Line and Systems Thinking approaches. As the Director of the STRONG Lab (Sustainable Technology, Research and Operations for the Next Generation), he focuses on integrating industrial ecology and Life Cycle Assessment (LCA) into additive manufacturing and engineering curricula. Prior to his academic career, he gained extensive industry experience in the Eolic (Wind) and Aerospace sectors, which informs his current work as the Capstone Coordinator for his department. An active member of the Engineering for One Planet (EOP) network and advisory board for EOP-MGP, Dr. Granda is a strong advocate for the belief that education is the fundamental driver for achieving a global sustainable future.

**Dr. Yang Zhang, Western Carolina University**

Dr. Yang Zhang is an Associate Professor in the School of Engineering + Technology at Western Carolina University. Dr. Zhang achieved his Ph.D. and M.S. degrees in Industrial Engineering from Texas Tech University. Dr. Zhang is passionate of conducting engineering education with innovative methods; he believes the best method for conveying the subject matter is the interest.

**Joao Paulo Jacomini Prioli, North Carolina Agricultural and Technical State University**

Dr. Joao Prioli is an Assistant Professor at North Carolina A&T State University. He received his Ph.D. and M.S. in Industrial and Systems Engineering from Wayne State University and holds a B.S. in Electrical Engineering from the University of Uberlândia. His research focuses on advancing automation solutions to support the circular economy, with a particular emphasis on smart manufacturing, CAD-based disassembly, and human-robot collaboration. His work explores data-driven modeling and automated disassembly processes to enable sustainable production and resource recovery.

**Oladayo Ariyo, North Carolina Agricultural and Technical State University**

Oladayo Ariyo is a doctoral candidate in the Applied Science and Technology Program with a concentration in Technology Management at North Carolina Agricultural and Technical State University. He received his Master's Degree in Applied Physical Science (Environmental Science) and his Bachelor's Degree in Biology from Georgia Southern University. He will graduate with his Ph.D. in May 2026.

Oladayo's research interests focus on Sustainable systems in Manufacturing and Material Science. He worked as a Research Assistant on Additive Manufacturing of Wood Polymer Composites, and served as a Teaching Assistant for the American Cutting Edge Initiative (ACE) sponsored by the Department of Defense's Industrial Base Analysis and Sustainment, covering 3D Printing and CNC Machining.

# Measuring Sustainability Mindsets in University Makerspaces: Design and Initial Validation of the Material Availability Policy (MAP) Survey Instrument


## Abstract

University makerspaces are increasingly recognized as experiential learning environments that foster innovation, prototyping, and hands-on engineering practice. However, they also contribute significantly to plastic waste—particularly through 3D printing. As institutions pursue ambitious sustainability goals, material availability policies within makerspaces offer a strategic yet underexplored opportunity to influence student behavior and mindset. This study investigates how pay-per-use, quantity limits, and bring-your-own-material (BYOM) policies shape sustainability and circularity attitudes among students in engineering and engineering technology programs.

Guided by the Engineering for One Planet (EOP) framework, which emphasizes integrating sustainability competencies into engineering education, this research explores how operational policies can serve as behavioral nudges that promote resource-conscious design and environmental stewardship. The study is grounded in the Technology Acceptance Model, Theory of Planned Behavior, and Social Cognitive Theory, the research also seeks to evaluate the validity and reliability of the Material Availability Policy (MAP) survey instrument designed to measure user experiences, attitudes, and behavioral intentions within this context. Constructs include perceived usefulness, ease of use, behavioral intention, environmental concern, and sustainability knowledge, alongside self-reported sustainable practices and barriers to adoption.

The survey is currently being deployed at two academic institutions in North Carolina, targeting undergraduate and graduate students, who actively use university makerspaces. Using a cross-sectional design and correlational analysis, the survey examines how different policy environments influence user behavior and mindset. Future phases will expand to additional institutions to enable cross-site comparisons and broader generalizability.

Preliminary findings will assess whether material availability policies encourage students to "Think before Do"—promoting intentional design, material reuse, and waste reduction. The study also explores equity implications and implementation challenges associated with cost-based and rationing policies, with attention to how these may affect access and participation across diverse user populations.

By intersecting makerspace policy design with the EOP framework, this research contributes empirical evidence to the evolving field of sustainable engineering education while validating psychometric tools for behavioral assessment. It offers actionable insights for administrators seeking to align makerspace operations with institutional sustainability goals, while enhancing student learning through real-world resource management. Ultimately, the study positions makerspaces as transformative platforms for cultivating sustainability and circularity competencies in future engineers.

## Introduction

University makerspaces have become essential hubs for experiential learning, enabling students to engage in hands-on design, prototyping, and innovation. These spaces align with pedagogical models that emphasize active learning and design thinking. However, the environmental footprint of makerspaces, particularly the generation of plastic waste from additive manufacturing, poses a significant challenge to institutional sustainability goals [1], [2]. As universities pursue ambitious carbon neutrality and waste reduction targets, operational strategies within makerspaces must evolve to address these concerns.

Despite growing interest in sustainability within engineering education, empirical evidence evaluating the effectiveness of makerspace material availability policies remains scarce. Existing literature is dominated by descriptive case studies and environmental assessments, with limited attention to policy-driven behavioral interventions [3], [4]. Policies such as pay-per-use pricing, quantity limits, and bring-your-own-material (BYOM) approaches are frequently discussed in practitioner forums but lack rigorous evaluation in academic research [1], [5]. This gap leaves administrators without evidence-based guidance for aligning makerspace operations with sustainability objectives.[1], [2], [3], [4]

The primary focus of this research is to detail the systematic design and initial application of a newly developed survey instrument intended to evaluate how material availability policies (MAP) function as behavioral nudges within university makerspaces. This work explicitly maps the survey's constructs to the Engineering for One Planet (EOP) framework, ensuring that sections on policy experience and sustainability behavior directly measure core competencies such as Systems Thinking, Materials Selection, and Environmental Literacy. Furthermore, it is important to note that the preliminary data presented in this study serve primarily to evaluate the instrument's suitability by analyzing its reliability, construct validity, and factor structure. By establishing this psychometric foundation through a pilot deployment at two North Carolina institutions, this research provides a replicable roadmap for future phases that will employ higher sample populations and multi-institutional comparisons to broaden the generalizability of these findings.

Preliminary results obtained from the initial deployment of the instrument indicate that while students acknowledge the importance of resource conservation, their actual material consumption is significantly more sensitive to "pay-per-use" and "quantity limit" policies than to purely voluntary sustainability actions. These findings suggest that institutional policy mechanisms are critical for bridging the sustainability intention and behavior gap in makerspaces. By identifying which policy "nudges" most effectively promote resource-conscious design, this research provides an empirical basis for integrating Engineering for One Planet (EOP) competencies into the curriculum, moving beyond theoretical advocacy to measurable student outcomes[6].

## Methodology

### Research Design

This study employs a cross-sectional survey design to examine the relationship between material availability policies and sustainability-related attitudes and behaviors among university makerspace users. The research is guided by the Technology Acceptance Model (TAM) Figure 1b; which predicts the adoption of new technology or processes based on perceived usefulness and perceived ease of use[7], [8], Theory of Planned Behavior (TPB) Figure 1c; which stipulates that the predictor of behavior is behavioral intention[9], and Social Cognitive Theory (SCT) Figure 1d; which explains how people learn and change behavior through a continuous interaction between personal factors, behavior, and environment[10], which collectively inform the measurement of perceived usefulness, ease of use, behavioral intention, and environmental concern [11], [12]. Also, the survey instrument was designed using the Engineering for One Planet (EOP) Framework Figure 1a as a theoretical framework[13], [14], [15]. Sentiment analysis was performed on the data using Likert scale questionnaires with single and multi-select format.

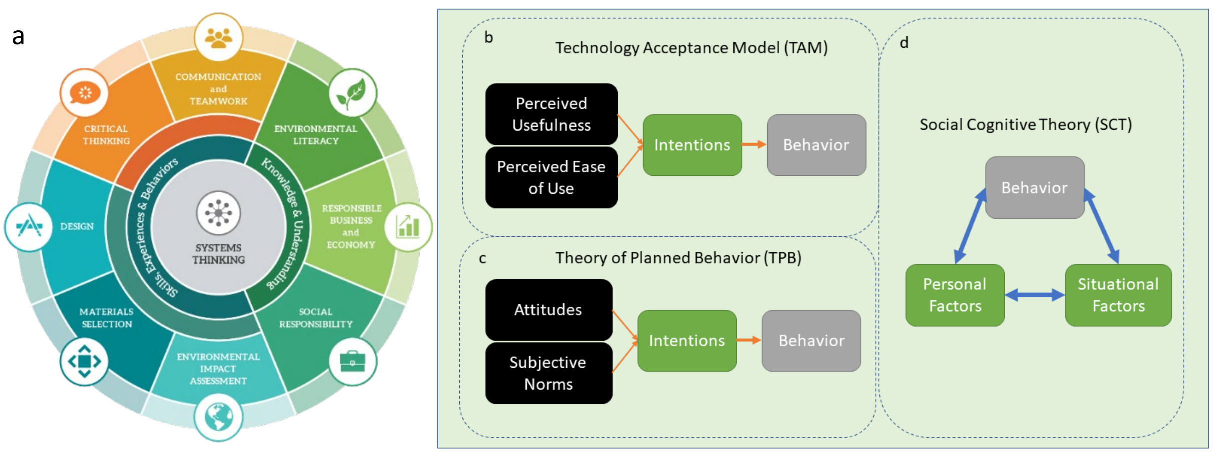


Figure 1. **(a) Engineering for One Planet Framework Graphic. Adapted from [15]. (b) Technology Acceptance Model (TAM)[7]. (c) Theory of Planned Behavior (TPB)[9]. (d) Social Cognitive Theory (STC)[10]**.

Institutional Review Board (IRB) approval was obtained from North Carolina Agricultural and Technical State University (NCA&T) and Western Carolina University (WCU).

- **NC A&T:** A large research-intensive university with separated engineering and engineering technology programs and multiple siloed "faculty-own" makerspaces.
- **WCU:** A large regional university with a unified engineering and engineering technology college with a focus on hands-on, industry-aligned prototyping labs and a big college-based free to use makerspace.

### Participants

The target population for this initial iteration includes undergraduate and graduate students enrolled in engineering and engineering technology programs who have used a university makerspace within the past 12 months[16]. Inclusion criteria required participants to be at least 18 years old and able to provide informed consent. Faculty and staff were excluded from this phase to maintain focus on student experiences. All participants were given an option to opt-in to a $25 amazon gift card drawing at the end of the survey, if the participant opted in it would directed to a new survey to provide contact information. This separate survey help maintain the anonymity of the responses in the MAP survey.

**Instrument**

As a central contribution to this work, the systematic development and detailed mapping of the Material Availability Policy (MAP) Sustainability Makerspace Survey serves as the primary outcome of this research. By providing a complete organizational structure of the survey, including the specific questions, response scales, and their direct alignment with Engineering for One Planet (EOP) competencies, this paper offers a transparent and replicable tool for the engineering education community. Sharing this instrument components is intended to expand their reach across diverse academic institutions, fostering a collaborative environment where the tool can be utilized, validated, and iteratively improved by other researchers and practitioners. Ultimately, this open dissemination aims to enhance the collective ability of makerspace managers and educators to measure and cultivate resource-conscious design habits in future engineers through evidence-based administrative interventions.

The survey instrument was developed through an iterative process to evaluate student mindsets regarding material availability. After a pilot to ensure clarity, the final instrument was deployed in five distinct sections following the initial demographics.

The Material Availability Policy (MAP) Sustainability Makerspace Survey was developed using Qualtrics and structured into five major blocks:

- **(Section C) Consent Block:** Provided study purpose, confidentiality assurances, and voluntary participation details.
- **(Section D) Demographics and Makerspace Usage:** Captured affiliation, program type, frequency of makerspace use, project types, and skill level.
- **(Section 2) Current Policy Experience:** Assessed perceptions of existing material policies (free access, pay-per-use, BYOM, quantity limits).
- **(Section 3) Sustainability Behavior Assessment:** Measured practices such as waste minimization, material reuse, and design optimization using Likert scales.
- **(Section 4) Policy Acceptance and Perceived Effectiveness:** Included TAM-based constructs (perceived usefulness, ease of use) and behavioral intention toward implementing new policies.
- **(Section 5) Open-Ended Questions:** Gathered qualitative insights on barriers, suggestions, and concerns.

Table 1 provides a complete organizational structure for the survey, including the specific possible responses and answer scales for each question.

**Table 1. Survey Instrument Questions, type and Response Options**

| ***ID*** | ***Question Text*** | ***Question Type*** | ***Possible Responses (Options)*** |
|---|---|---|---|
| ***C1*** | Consent Agreement: Do you agree to continue? | Single Select | I agree; I do not want to continue. |
| ***D1*** | What is your primary affiliation with the university? | Single Select | Undergraduate student; Graduate student; Faculty; Staff. |
| ***D2*** | I am part of a(n)? | Single Select (+ Text) | Engineering Technology Program; Engineering Program; Other (please specify). |
| ***D3*** | How frequently do you use a makerspace in your university? | Single Select | Daily; Weekly; Monthly; A few times per semester. |
| ***D4*** | What types of projects do you primarily work on? | Multiple Select | Course assignments; Personal projects; Research projects; Prototyping for entrepreneurship; Repairs/modifications; Other. |
| ***D5*** | Which equipment/areas do you use most frequently? | Multiple Select (Top 3) | 3D printers; Laser cutters; Electronics bench; Woodworking tools; Textile/sewing; Metalworking; Computer workstations; Other. |
| ***D6*** | How would you rate your overall skill level? | Single Select | Beginner; Intermediate; Advance; Expert. |
| ***2.1*** | What is the current material cost structure? | Single Select (+ Text) | All free; Pay-per-use; Mixed; BYOM required; Unsure; Other. |
| ***2.2*** | How are pay-per-use costs typically charged? | Single Select (+ Text) | Per gram; Flat fee per project; Time-based; No pay-per-use system; Other. |
| ***2.3*** | Are there quantity limits on material usage? | Single Select | Yes, strict; Yes, flexible; Informal guidelines only; No limits; Unsure. |
| ***2.4*** | How often do you bring your own materials? | Single Select | Always; Often (>75%); Sometimes (25-75%); Rarely (<25%); Never. |
| ***2.5*** | What motivates you to bring your own materials? | Multiple Select | Cost savings; Specific material requirements; Sustainability; Material quality; Policy requirements; N/A. |
| ***2.6*** | Have you experienced these policy-related situations? | Multiple Select | Project delayed; Changed design; Shared materials; Reused materials; Project incomplete; None of these. |
| ***2.7*** | How clear are the current material usage policies? | 5-pt Likert | Extremely unclear (1) to Extremely clear (5). |
| ***2.8*** | How fair and reasonable are the current policies? | 5-pt Likert | Extremely unfair/unreasonable (1) to Extremely fair/reasonable (5). |

| | | | |
|---|---|---|---|
| ***3.1*** | How important is sustainability to you personally? | 5-pt Likert | Not at all important (1) to Extremely important (5). |
| ***3.2*** | How often do you consider environmental impact? | Single Select | Always; Often; Sometimes; Rarely; Never. |
| ***3.3*** | Which sustainable practices do you currently use? | Multiple Select | Minimize waste; Reuse failed prints; Design for disassembly; Choose recyclable; Use biodegradable; Share leftovers; Optimize designs; None. |
| ***3.4*** | **Frequency of Actions:** (Minimize waste; Reuse failed prints; Help others optimize; Consider lifecycle) | Matrix (Frequency) | Never (1); Rarely (2); Sometimes (3); Often (4); Always (5). |
| ***3.5*** | What barriers prevent you from being more sustainable? | Multiple Select (+ Text) | Lack of knowledge; Time; Cost; Limited material options; Peer norms; Technical limitations; No barriers; Other. |
| ***3.6*** | How much material waste do you estimate you generate? | Single Select | Almost none (>95% util.); Minimal (80-95%); Moderate (60-80%); Significant (40-60%); High (>40% waste). |
| ***3.7*** | What do you typically do with leftover materials? | Single Select (+ Text) | Leave for others; Take home; Regular trash; Recycling; Return to storage; Other. |
| ***3.8*** | **Knowledge level regarding:** (Sustainable design; Recyclability; Waste reduction; Impact) | Matrix (Knowledge) | Not knowledgeable at all (1) to Extremely knowledgeable (5). |
| ***3.9*** | Have you changed making practices for sustainability? | Single Select | Yes (significantly, somewhat, or minimally); No (but I plan to); No (and I don't plan to). |
| ***3.10*** | How often do you discuss sustainability with others? | Single Select | Frequently; Occasionally; Rarely; Never. |
| ***4.1-4.4*** | **Perceived Usefulness/Ease:** (Pay-per-use; Quantity limits; BYOM policies) | Matrix (Agreement) | Strongly disagree (1); Somewhat disagree (2); Neither agree nor disagree (3); Somewhat agree (4); Strongly agree (5). |
| ***4.5*** | **Behavioral Intent:** (Support for pay-per-use; Limits; BYOM; Adapting practices) | Matrix (Agreement) | Strongly disagree (1) to Strongly agree (5). |
| ***4.6*** | What cost levels would you consider acceptable? | Single Select | \$0.01-0.05/g; \$0.06-0.10/g; \$0.11-0.20/g; \$0.21-0.50/g; >\$0.50/g; No pay-per-use; Prefer cost based on material type. |
| ***4.7*** | What are reasonable free material weekly limits? | Single Select | 100g or less; 101-250g; 251-500g; 501-1000g; >1000g; No limits. |

| | | | |
|---|---|---|---|
| ***4.8*** | How should new policies be implemented? | Single Select | Immediately; Gradual phase-in; Pilot program; Optional participation; Should not be implemented. |
| ***4.9*** | What support would you need for new policies? | Multiple Select | Training; Cost tools; Selection guidance; Peer mentoring; Flexible payment; None. |
| ***4.10*** | **Perceived Barriers:** (Financial; Complexity; Resistance; Technical; Administrative) | Matrix (Barrier) | Not a Barrier (1); Minor Barrier (2); Moderate Barrier (3); Major Barrier (4). |
| ***4.11*** | **Predicted Improvement:** (Waste; Awareness; Quality; Equity; Management learning) | Matrix (Change) | Much worse (1); Somewhat worse (2); No change (3); Somewhat better (4); Much better (5). |
| ***4.12*** | **Overall Support:** (Pay-per-use; Limits; BYOM; Hybrid approach) | Matrix (Support) | Strongly Oppose (1) to Strongly Support (5). |
| ***5.1*** | Open-Ended Questions (Additional approaches; Concerns; General comments) | Text Entry | Open text (Short and precise answers). |
| ***End*** | I am willing to provide my email for the drawing. | Single Select | Yes (Branch to email form); No. |

**EOP Framework Mapping**

The design of the "Material Availability Policies (MAP) in University Makerspaces" survey is grounded in the EOP Framework's essential learning outcomes. Table 2 maps the survey sections to the Engineering for One Planet (EOP) Framework, identifying the core topics and specific learning outcomes that each section evaluates.

**Current Policy Experience:** This section assesses how students perceive existing business models (free vs. pay-per-use). This aligns with the EOP goal of Responsible Business and Economy, which requires engineers to operate as environmentally and socially responsible as possible within the constraints of a business model.

**Table 2: Mapping - Makerspace Survey vs. EOP Framework**

| Survey Section | EOP Framework Topic | Learning Outcome | Relevant Outcome Description |
|---|---|---|---|
| Current Policy Experience | Responsible Business and Economy | Core #3 | Demonstrate awareness that different revenue and business models can positively or negatively influence environmental and social systems. |

| | | | |
|---|---|---|---|
| Sustainability Behavior Assessment | Design | Core #2 | Design for the environment and society based on discipline-specific technical skills (e.g., repairability, durability, disassembly, and reuse). |
| | Materials Selection | Core #1 | Identify potential impacts of materials (emissions, toxicity, etc.) from raw material extraction through end of life. |
| | Environmental Literacy | Core #5 | Examine data about environmental issues including waste management, toxicity, and scarcity. |
| Policy Acceptance & Effectiveness | Systems Thinking | Core #2 | Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations). |
| | Communication and Teamwork | Core #1 | Champion and advocate for organizational and societal change; sell, pitch, and explain ideas. |
| Open-Ended Questions | Critical Thinking | Core #1 | Define problems comprehensively with consideration of consequences, unintended and intended. |
| | Critical Thinking | Advanced #6 | Prioritize appropriate solutions based on the context of the problem, in collaboration with other stakeholders and experts. |

**Sustainability Behavior Assessment:** By measuring practices like waste minimization and design optimization, this section directly evaluates the EOP Design outcomes. Specifically, it tracks if students can execute technical analyses to choose strategies that maximize positive environmental impacts. It also maps to Environmental Literacy by examining how students handle data regarding waste management.

**Policy Acceptance & Perceived Effectiveness:** This section utilizes the Technology Acceptance Model (TAM) to measure perceived usefulness and ease of use. In the EOP Framework, this maps to Systems Thinking, as students must think of the interconnectedness between human actions (using materials) and global environmental consequences (waste). It also relates to Communication and Teamwork by evaluating if students will advocate for organizational change regarding new sustainability-focused values.

**Open-Ended Questions:** These qualitative prompts allow students to identify barriers and suggestions. This maps to Critical Thinking outcomes, specifically the ability to define problems comprehensively while considering both intended and unintended consequences.

## Preliminary Results

The preliminary results from this pilot deployment serve as a critical validation of the Material Availability Policy (MAP) Sustainability Makerspace Survey instrument, demonstrating its functional utility in capturing the complex relationship between operational policies and student sustainability mindsets. The pilot findings successfully demonstrate the survey's ability to differentiate student sensitivity to various behavioral nudges, confirming that it can effectively measure how policy-driven constraints catalyze higher-level design intentionality and systems thinking. The alignment of these survey constructs with the Engineering for One Planet (EOP) framework validates the instrument as a robust, evidence-based tool for assessing the development of professional sustainability competencies in academic makerspace environments. Ultimately, these preliminary data points help establish the psychometric reliability of the instrument, positioning it as a replicable tool for institutions seeking to utilize operational policies not merely as administrative tools, but as pedagogical catalysts for sustainable engineering education.

### Demographics

While the survey deployment involved a substantial multi-institutional marketing effort, utilizing direct email invitations, LMS announcements, and physical signage within the makerspaces, the initial student response rate was lower than anticipated. This "low-N" result during the pilot phase provided critical early insights into student engagement with sustainability topics. Preliminary analysis suggests that the timing of the deployment during the end-of-term and examination period may have contributed to survey fatigue. Table 3 show the participant demographics.

- **Total Responses (N):** 13 completed surveys.
- **Affiliation:** 9 undergraduate students, 4 graduate students.
- **Programs:** Engineering Technology (majority), Engineering, Applied Science.
- **Usage Frequency:** 38% weekly, 23% daily, remainder monthly or less.

**Table 3: Participant Demographics**

| Category | Count | Percentage |
|---|---|---|
| **Undergraduate** | 9 | 69% |
| **Graduate** | 4 | 31% |
| **Engineering Tech** | 8 | 62% |
| **Engineering** | 4 | 31% |

### Current Policy Experience

The baseline data collected in Section 2 of the instrument provides a critical snapshot of the current material accessibility landscape. As illustrated in Figure 2, the predominant policy structure at the participating institutions is a "free-to-use" model, encompassing both personal and course-based projects. This open-access makerspace offers students considerable creative freedom; however, from a sustainability standpoint it lacks formal cost signals or scarcity nudges that would encourage more efficient use of resources.

Despite the overarching free-to-use structure, qualitative responses reveal nuanced hybridity in practice. For instance, students noted that while standard materials are provided at no cost, Bring-Your-Own-Material (BYOM) protocols are activated when a specific or specialized material is required for a project. In such cases, the responsibility for procurement shifts to the individual student. Furthermore, the survey identified an "inter-departmental budgetary framework," where specific academic courses utilize separate budgets to procure materials not currently stocked in the makerspace. These findings suggest that while the makerspace is perceived as a free resource, student design choices are occasionally limited by the available inventory, creating a "de facto" constraint that mirrors more formal sustainability policies.

- **Free Material Access:** 100% reported materials provided free by the institution.
- **Quantity Limits:** 46% indicated informal or flexible limits.
- **BYOM:** Rarely practiced; most students never bring their own materials.

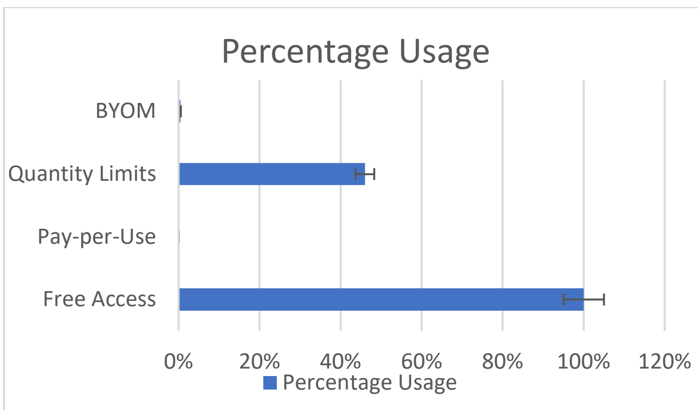


Figure 2: **Current Policy Structure**

**Sustainability Attitudes and Practices**

The data collected in this section reveals a significant discrepancy between student intentionality and current makerspace behavior. While 77% of respondents reported that sustainability is “Very Important” or “Extremely Important,” this high level of personal value does not consistently translate into active, habitual practice. For instance, although a majority of students express a desire to act sustainably, only a smaller fraction reported consistent engagement in sustainable practices. This suggests that while students possess the EOP Environmental Literacy mindset, the lack of formal institutional "nudges" or constraints in a free-to-use environment allows for a disconnect where sustainable desire remains high, but measurable behavior remains largely dormant or inconsistent.

Despite these positive attitudes, significant obstacles hinder the full integration of sustainable engineering practices. The survey identified "Lack of Knowledge" (62%) and "Technical Limitations" (54%) as the most prevalent barriers to deeper sustainability engagement. This results in a "value-action gap," where students' desire to design sustainably is obstructed by a lack of formal instruction, missed operations knowledge base or a lack of access to eco-friendly material alternatives. These results underscore a critical call to action for engineering educators: while students are motivated to participate in the circular economy, they require more robust technical training and enhanced makerspace capabilities, such as a more visible and wider variety of biodegradable filaments or waste-recycling infrastructure, to move from general intentionality to advanced EOP Materials Selection proficiency.

- **Importance of Sustainability:** 77% rated sustainability as “Very Important” or “Extremely Important.”
- **Practices:** Most common behaviors include minimizing material waste (85%) and optimizing designs (70%).
- **Barriers:** Lack of knowledge (62%) and technical limitations (54%) were most cited, followed by Time Constraints (38%).

**Policy Acceptance and Perceived Effectiveness**

The data regarding policy acceptance reveals a clear hierarchy in student preference, directly reflecting the perceived balance between institutional responsibility and individual burden. As shown in Figure 3, Quantity Limits emerged as the only policy model with majority support (54%). From a pedagogical standpoint, this suggests that students view moderate rationing as a "fair" constraint that encourages Systems Thinking, prompting more intentional design planning, without the immediate financial pressure associated with other models. This finding aligns with the EOP Responsible Business and Economy competency, as it forces students to operate within the physical constraints of a system while maintaining equitable access for all users.

In contrast, the Pay-per-Use model faced the highest level of resistance, with 46% of participants in opposition. Qualitative feedback suggests this resistance is rooted in the fear that cost-based signals would hinder the "fail-fast, learn-fast" innovation mindset essential to the makerspace experience. Furthermore, while Bring-Your-Own-Material (BYOM) received 38% support, it was tied to significant concerns regarding the EOP Social Responsibility pillar. Students identified that shifting the procurement burden to the individual creates a "pay-to-play" environment that could disadvantage low-income students. These results indicate that while students have a latent desire to practice sustainability, they are highly sensitive to the equity of the mechanism used to enforce it. The "value-action gap" identified earlier suggests that for a policy to be successful, it must be framed not as a punitive cost, but as a technical design challenge that mirrors real-world resource scarcity.

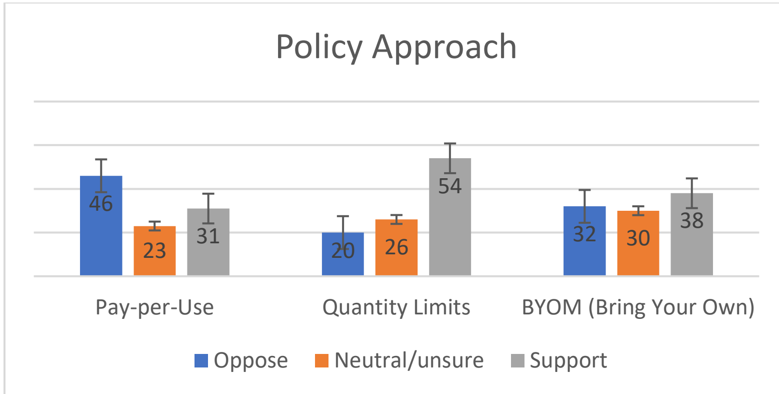


Figure 3: **Policy Support Levels**

**Discussion**

Overall, these results suggest that makerspace material policies function as a critical catalyst for Systems Thinking, fostering the circular economy mindset essential to contemporary industrial realities. These preliminary data points underscore the potential of such policies to exceed their role as mere administrative tools, serving instead as pedagogical instruments that reinforce the core tenets of the Engineering for One Planet (EOP) framework. By introducing intentional constraints, institutions can move students beyond simple technical application toward a more holistic evaluation of resource life cycles. Figure 4, shows a visual summary of the role that material availability policies could have if implemented on the design mindset of makerspace users.


Figure 4: **Material policies as a behavioral nudge**

Furthermore, the findings reveal a notable paradox in student engagement: while there is a robust baseline of sustainability awareness, engagement with formal conservation policies remains limited. One respondent said "*The makerspace needs to encourage students to design such that they minimize waste. Printing a 300g model and finding out the holes were spaced wrong is a common error and free materials encourage students to just trash the model and try again. If students pay they will be encouraged to print critical geometry to test fits and form instead of* *wasting materials printing large items that do not function as intended*". The current "free-to-use" model, while promoting accessibility, may inadvertently incentivize wasteful practices by removing the feedback loops necessary for responsible consumption. On the contrary, while Pay-per-Use models introduce a clear cost signal, they raise significant Social Responsibility concerns regarding equitable access. Participants expressed concerns that cost-related policies may impose financial strain or inadvertently reduce engagement with makerspace resources, potentially limiting project completion and willingness to participate. One respondent mentioned "*I am concerned with the possibility of having to spend money that I don't necessarily have on a college assignment. I understand it for personal prints but class assignments I don't like*" Another respondent said similarly, "*I feel that making cost a concern may limit students willingness to use the makerspace for their class projects…*". In this context, Quantity Limits combined with targeted educational interventions emerge as the most viable "middle-ground" strategy. This policy protects lower-income students by capping how much anyone can consume, while a pure "pay-per-use" model directly ties opportunity to ability to pay, so poorer students hit a financial ceiling much sooner. These mechanisms appear both more acceptable to the student population and potentially more effective at bridging the identified value-action gap, providing a structured yet equitable framework for sustainable engineering education. By providing a standardized, free allocation of material, institutions can protect students from lower socio-economic backgrounds from the "financial ceiling" imposed by cost-based models, thereby reframing resource constraints as shared technical challenges rather than individual economic burdens. This shift not only aligns makerspace operations with institutional sustainability goals but also fosters a more inclusive environment where the development of a circular economy mindset is accessible to the entire student population.

**Conclusion and Call to Action**

This paper has detailed the systematic development and preliminary deployment of a multi-institutional survey instrument designed to bridge the gap between makerspace management and the Engineering for One Planet (EOP) framework. The initial findings suggest that while engineering students possess a high degree of "Environmental Literacy," their ability to practice "Materials Selection" and "Systems Thinking" is heavily influenced by the institutional material policies in place. Specifically, quantity-based limits appear to be the most acceptable "behavioral nudge" for fostering resource-conscious design without hampering creativity or equity. By documenting the design and development of this instrument, this study provides a foundation for measuring how administrative structures can serve as pedagogical tools for sustainability.

There is an urgent need for engineering educators and makerspace managers to move beyond the role of service providers and act as architects of sustainable mindsets. We must recognize that the policies we choose, whether pay-per-use, quantity limits, or BYOM, are not just financial decisions; they are curricular interventions. Makerspace administrators and educators are encouraged to audit their makerspace accessibility models through the lens of the EOP framework, ensuring that resource constraints are utilized to trigger design optimization rather than simply managing budgets.

As initial actions-driven suggestions we advocate that current makerspace should:

- Pilot **hybrid policy models** combining moderate quantity limits with sustainability training.
- Implement **material tracking systems** to monitor usage and waste.
- Provide **educational resources** on sustainable design practices.
- Explore **filament recycling programs** to reduce plastic waste and showcase a circular economy example.

Future research should expand sample size, include multi-institutional comparisons, and employ longitudinal designs to assess behavioral change over time.

## References


[1] C. R. Forest, "The Invention Studio: A University Maker Space and Culture," *Advances in Engineering Education*, 2014.

[2] K. Dew and D. K. Rosner, *Designing with Waste: A Situated Inquiry into the Material Excess of Making*. Designing Interactive Systems, 2019.

[3] M. Ragazzi, *Parameters analysis for a sustainable management of solid waste in university buildings*. MATEC Web of Conferences, 2020.

[4] O.-R. Bobic, "Makerspaces as learning spaces for sustainable development. A systematic literature review," *Journal of Education and Science*, 2023.

[5] "Making Policies: An Analysis of Makerspace Policies at Academic Institutions."

[6] D. E. Salinas-Navarro, "Experiential Learning for Circular Operations Management in Higher Education," *Sustainability*, 2024.

[7] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *MIS quarterly*, pp. 319–340, 1989.

[8] V. Venkatesh and F. D. Davis, "A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies," *Management Science*, vol. 46, no. 2, pp. 186–204, Feb. 2000, doi: 10.1287/mnsc.46.2.186.11926.

[9] I. Ajzen, "The theory of planned behavior: Frequently asked questions," *Human Behav and Emerg Tech*, vol. 2, no. 4, pp. 314–324, Oct. 2020, doi: 10.1002/hbe2.195.

[10] A. Bandura, "Social cognitive theory of moral thought and action," in *Handbook of moral behavior and development*, Psychology press, 2014, pp. 45–103.

[11] E. Barrella, E. P. Spratto, E. Pappas, and R. Nagel, "Developing and validating an individual sustainability instrument with engineering students to motivate intentional change," *Sustainability*, vol. 10, no. 8, p. 2885, 2018.

[12] L. Pollettini_Marcos, J. Linsey, M. Aleman, R. Nagel, K. Douglas, and E. Holloway, "Development and Validation of Learning Through Making Instrument (LMI) Project Overview," ASEE Conferences, 2024. [Online]. Available: https://par.nsf.gov/servlets/purl/10567476

[13] V. Smith, S. Shrestha, A. Welker, and K. Sample-Lord, "Including Principles of Sustainability in Design by Implementing the Engineering for One Planet Framework,"

presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Feb. 07, 2024. [Online]. Available: https://peer.asee.org/including-principles-of-sustainability-in-design-by-implementing-the-engineering-for-one-planet-framework

[14] A. Schulz *et al.*, "A Toolkit for Expanding Sustainability Engineering Utilizing Foundations of the Engineering for One Planet Initiative," *ASEE Annual Conference and Exposition, Conference Proceedings*, 2023.

[15] "The EOP Framework," Engineering For One Planet. Accessed: Apr. 01, 2024. [Online]. Available: https://engineeringforoneplanet.org/transforming-curricula/eop-framework/

[16] S. Weiner, M. Lande, and S. S. Jordan, "What Have We 'Learned' from Maker Education Research? A Learning Sciences-base Review of ASEE Literature on the Maker Movement," presented at the 2018 ASEE Annual Conference & Exposition, Jun. 2018.