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Is Access Enough? Examining the Impact of Additive Manufacturing Access on Student Design Self-Efficacy in ABET-Compliant Mechanical Engineering Curriculum

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Peter Fabe is a doctoral student in Design Science at the University of Michigan, where his research spans additive manufacturing systems, sustainable design, and engineering education. His work examines how emerging manufacturing technologies can be meaningfully integrated into undergraduate curricula to build student competency and confidence alongside traditional fabrication methods.

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Abstract

As additive manufacturing (AM) technologies become increasingly prevalent in engineering education, their proper integration within core curricula is critical to preparing students for modern design and fabrication challenges. This study examines the educational impact of classroom-based fused filament fabrication (FFF) 3D printing in a mandatory second-year mechanical engineering design and manufacturing course that fulfills the ABET manufacturing requirement. A mixed-methods survey with paired responses and Wilcoxon signed-rank tests for pre- and post-intervention was used. Through surveys and project analyses of 159 undergraduate students, the study shows that having additive manufacturing equipment located within the lab increases AM utilization compared to a centralized campus makerspace, raising moderate use from 22% to 56% of project teams and reducing nonuse from 41% to 11%. However, despite high physical access to 3D printers, student self-efficacy with AM tools remains significantly lower (17–18% report low confidence) than with traditional manufacturing tools such as mills, lathes, and computer-aided design (CAD) (<2% report low confidence). Analysis of pre- and post-course self-assessments across both tool-related and design-related domains demonstrates statistically significant improvements in all areas (Wilcoxon Signed-Rank Tests, all $p < .001$). While the 3D printing intervention produced meaningful gains, the magnitude of improvement was smaller than in the more familiar domains. These findings indicate that physical access alone does not translate into confidence or effective use of AM in student projects. Structured, scaffolded learning experiences and targeted instructional interventions are identified as critical factors for boosting student competence and engagement with manufacturing technologies. The study recommends integrating mandatory, guided AM learning experiences that complement traditional manufacturing technologies, emphasizing iterative design, hands-on practice, and reflective learning.

Introduction

According to the National Academy of Sciences, engineering education must prepare students to engage in the full engineering process, "from concept to design to build," to meet modern industry demands [1]. The report notes that traditional undergraduate mechanical engineering curricula have largely focused on conventional, often subtractive manufacturing processes, with most students receiving only limited exposure to fabrication beyond basic lab exercises or elective courses [1]. Consequently, the National Academy emphasizes that "all undergraduate engineering students, and especially those in mechanical engineering, need to learn about manufacturing and advanced manufacturing" [1], and that curricula should include "laboratory 'assignments' to build practice, with access to…shop equipment or advanced manufacturing services" [1] to develop essential hands-on skills for both traditional and emerging manufacturing technologies.

Given this context, it is important to assess the state of current curricular requirements and accreditation standards to understand how mechanical engineering programs ensure students gain the knowledge and skills needed to connect design with fabrication. ABET-accredited mechanical engineering programs similarly require that graduates "apply engineering design to produce solutions that meet specified needs" [2] and explicitly expect students to gain knowledge in "materials, manufacturing processes, and the application of engineering design to the realization of physical systems, components, or processes" [3]. Together, the National Academies' guidance and ABET requirements underscore the dual importance of design and realization in modern mechanical engineering education.

Additive manufacturing (AM) has continued to emerge as a more prevalent advanced manufacturing technology, offering students opportunities to prototype and fabricate complex geometries that are not feasible with traditional subtractive methods. Ford and Minshall's review of AM in education [4] highlights that AM is increasingly integrated into engineering curricula, offering students valuable experience with prototyping and iterative design. However, their work focuses primarily on AM-centric deployments and does not address how fused filament fabrication (FFF) 3D printing integrates into required, mixed-technology manufacturing courses alongside traditional subtractive processes, leaving a gap in understanding the effects of access on student self-efficacy and utilization in that context. This study aims to evaluate whether increased in-laboratory access to FFF printers drives self-efficacy and utilization in a required sophomore mechanical engineering design and manufacturing course.

Literature Review

Recent research consistently emphasizes the value of an early, hands-on approach to AM education, highlighting laboratory, project-based, and iterative prototyping experiences as key to effective learning [5], [7]–[9], [11], [12]. Many studies analyze the pedagogical benefits of teaching AM through both opportunistic and restrictive design for additive manufacturing (DfAM) principles, encouraging students to leverage creative design freedoms while also addressing manufacturability [9], [12]. Teaching methods that integrate practical design challenges and direct interaction with AM technologies have proven especially effective in building both objectively measured and self-reported competency outcomes [5], [7], [11].

However, most of these efforts are conducted within an additive-centric or additive-promoting context, with AM presented as a standalone topic or as a preferred technology, often with limited reference to traditional or subtractive manufacturing processes [5], [6], [10], [11]. While such approaches are beneficial for preparing students for emerging AM industry needs, they leave a gap in understanding how AM knowledge integrates with conventional manufacturing in the broader engineering curriculum [6], [10]. Exploring how embedding AM concepts and lab experiences alongside traditional processes affects design and tool self-efficacy is crucial for developing holistic engineers who can make informed process selections across a wide range of manufacturing contexts.

Context

The study was conducted in a required sophomore-level mechanical engineering course focused on design and manufacturing fundamentals at a Midwestern public R1 university. The course serves as the first in a sequence of design-oriented courses in the curriculum and is taken after students have completed foundational coursework in mathematics and introductory engineering principles. This course satisfies ABET's mechanical engineering-specific manufacturing requirements [3].

Instruction is delivered through a combination of lectures and labs, promoting active engagement and application of design and manufacturing concepts. Labs meet twice a week in one-hour sessions. The course typically enrolls 160 students per semester across lab sections capped at 20 students each, further divided into 4 teams per section. Each team builds a Robot Machine Player (RMP) to compete in a cooperative game where teams score points through completing tasks such as moving around the game arena, depositing items in certain spaces, or manipulating aspects of the arena.

The course emphasizes both conceptual and hands-on learning, integrating computer-aided design (CAD), engineering physics, and basic manufacturing processes with practical fabrication skills. Laboratory sessions reinforce CAD modeling, technical sketching, engineering analysis, design review, and machine tool practice. Students have supervised open access to the undergraduate machine shop and to the lab during regularly scheduled weekly hours.

Prior to the intervention, traditional manufacturing tools, including manual mill and lathe, were integrated through mandatory, structured activities. Each student completed a supervised mill and lathe training exercise, followed by a graded assignment requiring them to design a CAD model and fabricate a part using the manual mill. These activities ensured repeated, hands-on exposure to traditional tools with guidance from instructors during scheduled lab hours. In contrast, 3D printing was not required for any project assignments; use of additive manufacturing was optional and unstructured, limited to parts students chose to fabricate via the centralized makerspace.

Intervention

The intervention consisted of installing a shelf of nine Bambu Lab A1 Mini 3D printers (Figure 1) within the engineering course laboratory space, starting in the "Semester of Intervention." This replaced the previous arrangement in which students fabricated 3D printed parts at a centralized campus makerspace, where printed parts were submitted to a queue and managed by a staff member. With the printers located in the classroom lab, students had direct access to 3D printing resources for all project activities. The in-lab setup enabled students to set up, observe, and troubleshoot prints in real time, receive immediate support from instructors, and iterate on their designs during scheduled and open lab hours. There were nine printers available for 32–36 teams per semester, with four printers reserved per lab section during each section's scheduled two-hour weekly lab time. No additional training or curricular AM content was implemented beyond an optional presentation on navigating the slicing software. There was no requirement to use AM at any point in the course.

Figure 1. 3D printer shelf installed in lab

Methods

Team utilization of 3D printing was scored on the following ordinal scale, determined from project documentation and fabrication records:

- No Utilization (N): No 3D printed parts produced
- Low Utilization (L): Parts produced not essential to functionality, or traditionally manufacturable in fewer than five steps
- Moderate Utilization (M): One unique part produced that is critical to robot functionality (may include additional non-critical or traditionally manufacturable parts)
- High Utilization (H): Two or more unique parts produced that are critical to robot functionality

Figure 2 shows examples of team utilization of 3D printing on their RMP.

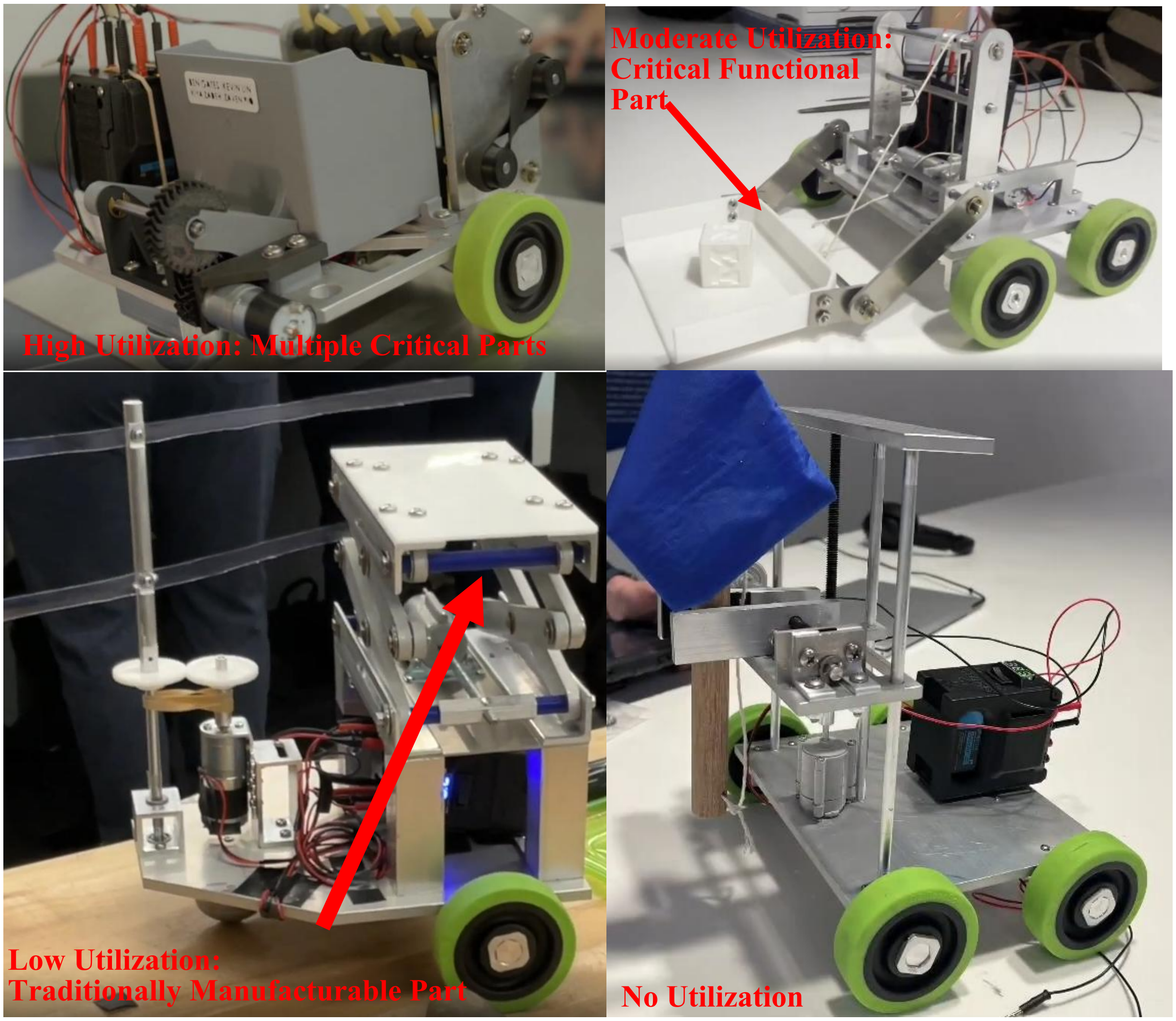

Figure 2. AM utilization by team robot: high utilization (top left), moderate utilization (top right), low utilization (bottom left), and no utilization (bottom right)

A survey instrument was developed to assess student self-efficacy for fabrication tools and design tasks, based on established best practices for engineering education research. Items were designed to measure both general tool familiarity and specific design competencies using clear, behaviorally anchored response scales. The development process included alignment with two previously validated self-efficacy survey instruments for design education [13] and for AM design specifically [14]. Question wording, content domains, and Likert scale definitions were closely modeled after these instruments to enhance validity and comparability, while ensuring relevance to the context of a mechanical engineering general design and manufacturing course.

Student self-efficacy for tools and design tasks was measured using two survey items, each with a five-point Likert scale:

Tool Self-Efficacy (“How do you feel about the following tools?” for mill, lathe, CAD, 3D printing):

- 1: I have never heard of it
- 2: I have heard of it but never used it
- 3: I could use it with basic instruction
- 4: I could use it unaided
- 5: I can teach others to use it

Design Self-Efficacy (“Rate your perceived ability to fabricate a part with proper dimensional tolerance or to create an object in CAD without a physical reference object”):

- 1: I could not complete this
- 2: I would require regular guidance to complete this
- 3: I can complete this with occasional guidance
- 4: I can complete this mostly independently
- 5: I can complete this independently

For both survey questions, responses of 1 or 2 were classified as low self-efficacy. Responses of 3 or higher were classified as adequate or high self-efficacy.

Surveys were administered through Qualtrics at the beginning and end of each semester for completion credit. Permission to use de-identified survey responses was requested at the end of each survey. Team utilization scores were compiled following project completion. Chi-square tests of independence were used to examine differences in team 3D printing utilization rates and category distributions across semesters. Self-efficacy means and average Likert point increases were calculated for each domain, and the prevalence of low self-efficacy responses was assessed. Score distributions for pre- and post-intervention semesters were visualized using box and whisker plots.

Pre- and post-intervention surveys captured self-assessed competence across four domains: Mill, Lathe, CAD, and 3D Printing. For each domain, students rated both tool-related and design-related skills on a five-point Likert scale. Wilcoxon Signed-Rank Tests were applied to each domain and context to evaluate statistically significant changes in self-assessment scores from pre- to post-intervention. This non-parametric approach was chosen because it appropriately accounts for the paired nature of the data and the ordinal measurement level of the survey items, providing a robust indication of skill improvements without assuming normality.

The Kaiser–Meyer–Olkin (KMO) measures indicated meritorious sampling adequacy for the pre-survey (KMO = 0.854) and acceptable sampling adequacy for the post-survey (KMO = 0.708). Bartlett’s test of sphericity was significant for both surveys ($p < 0.001$), supporting the suitability of the data for factor analysis.

Results

Utilization of AM by robot design teams was examined across three time points: the Pre-Intervention Semester, the Semester of Intervention, and the Second Semester of Intervention. The distribution of teams across utilization categories by semester is presented in Table 1.

Chi-square tests of independence were conducted to evaluate differences in utilization rates across semesters for each utilization category. For teams reporting no utilization, a significant difference in proportions was observed, $\chi^2(2, N = 104) = 7.87$, $p = .020$. The number of teams reporting no use of 3D printing decreased from 13 in the Pre-Intervention Semester to 11 during the Semester of Intervention and 4 in the Second Semester of Intervention. Low utilization remained stable at 5 teams per semester and did not differ significantly across time, $\chi^2(2, N = 104) = 0.054$, $p = .973$.

Moderate utilization showed a significant increase over time, rising from 7 teams in the Pre-Intervention Semester to 10 during the Semester of Intervention and 20 in the Second Semester of Intervention, $\chi^2(2, N = 104) = 8.11$, $p = .017$. High utilization changed from 7 teams in the Pre-Intervention Semester to 10 in the Semester of Intervention and 7 in the Second Semester of Intervention, but this change was not statistically significant, $\chi^2(2, N = 104) = 0.573$, $p = .751$. Trends in utilization across all categories are illustrated in Figure 3.

Overall, these results indicate a marked reduction in teams reporting no utilization of AM and a significant increase in moderate utilization across the three semesters. Low utilization remained stable, and the observed changes in high utilization were not statistically significant. Detailed utilization patterns are provided in Table 1 and further illustrated in Figure 3.

Table 1. Number of teams by utilization category and semester

Utilization Category	Pre-Intervention Semester	Semester of Intervention	Second Semester of Intervention
No Utilization (N)	13 (40.6%)	11 (30.6%)	4 (11.1%)
Low Utilization (L)	5 (15.6%)	5 (13.9%)	5 (13.9%)
Moderate Utilization (M)	7 (21.9%)	10 (27.8%)	20 (55.6%)
High Utilization (H)	7 (21.9%)	10 (27.8%)	7 (20.6%)
Total	32	36	36

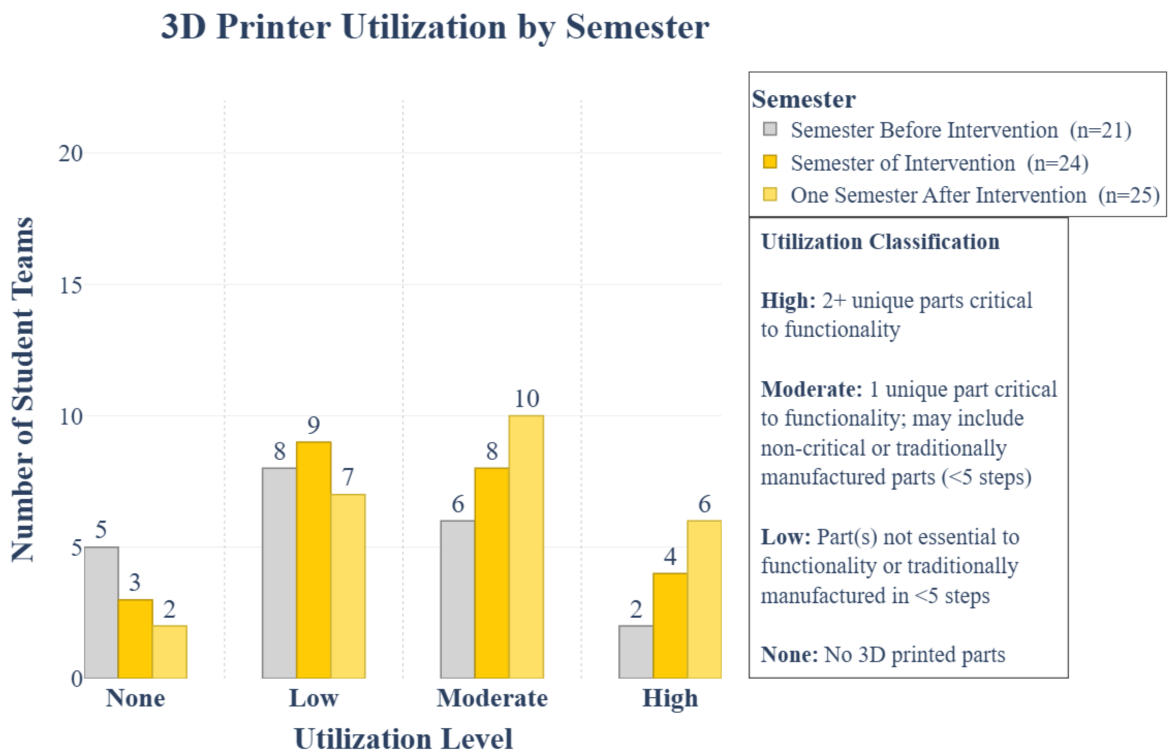

Figure 3. AM utilization per team by semester (Pre-Intervention: n = 32 teams; Semester of Intervention: n = 36 teams; Second Semester of Intervention: n = 36 teams)

Student self-efficacy for both tool and design skills was measured using five-point scales (see Methods). There were 159 individual responses over the two semesters of intervention. Note that gains in mill, lathe, and CAD self-efficacy reflect the mandatory individual exercises for those tools that were present in all semesters, including the Pre-Intervention Semester; these domains serve as a within-course reference for comparison with the unstructured 3D printing condition. Average self-efficacy scores increased substantially for every domain after the intervention, including mill (2.24 to 4.45), lathe (2.13 to 4.27), CAD (3.06 to 4.32), 3D printing tool use (2.75 to 3.51), CAD design (2.97 to 4.47), and 3D printing design (2.42 to 3.56). These increases are also evident in the distributions displayed in Figure 4.

Table 2. Pre-semester and post-semester self-efficacy scores by domain (tool vs. design) and technology across the Semester of Intervention and Second Semester of Intervention. Refer to the Methods for the Likert scoring definitions. SD: Standard Deviation. SE: Standard Error

Domain / Skill	Pre (Mean)	SD	SE	Post (Mean)	SD	SE	Mean Increase
Mill (Tool)	2.24	0.79	0.06	4.45	0.66	0.05	2.21
Lathe (Tool)	2.13	0.78	0.06	4.27	0.74	0.06	2.14
CAD (Tool)	3.06	1.07	0.08	4.32	0.65	0.05	1.26
3DP (Tool)	2.75	0.98	0.08	3.51	1.03	0.08	0.76
CAD (Design)	2.97	1.19	0.09	4.47	0.74	0.06	1.50
3DP (Design)	2.42	1.09	0.09	3.56	1.21	0.10	1.14
Mill (Design)	2.22	1.04	0.08	4.60	0.57	0.05	2.38
Lathe (Design)	2.01	0.87	0.07	4.43	0.70	0.06	2.42

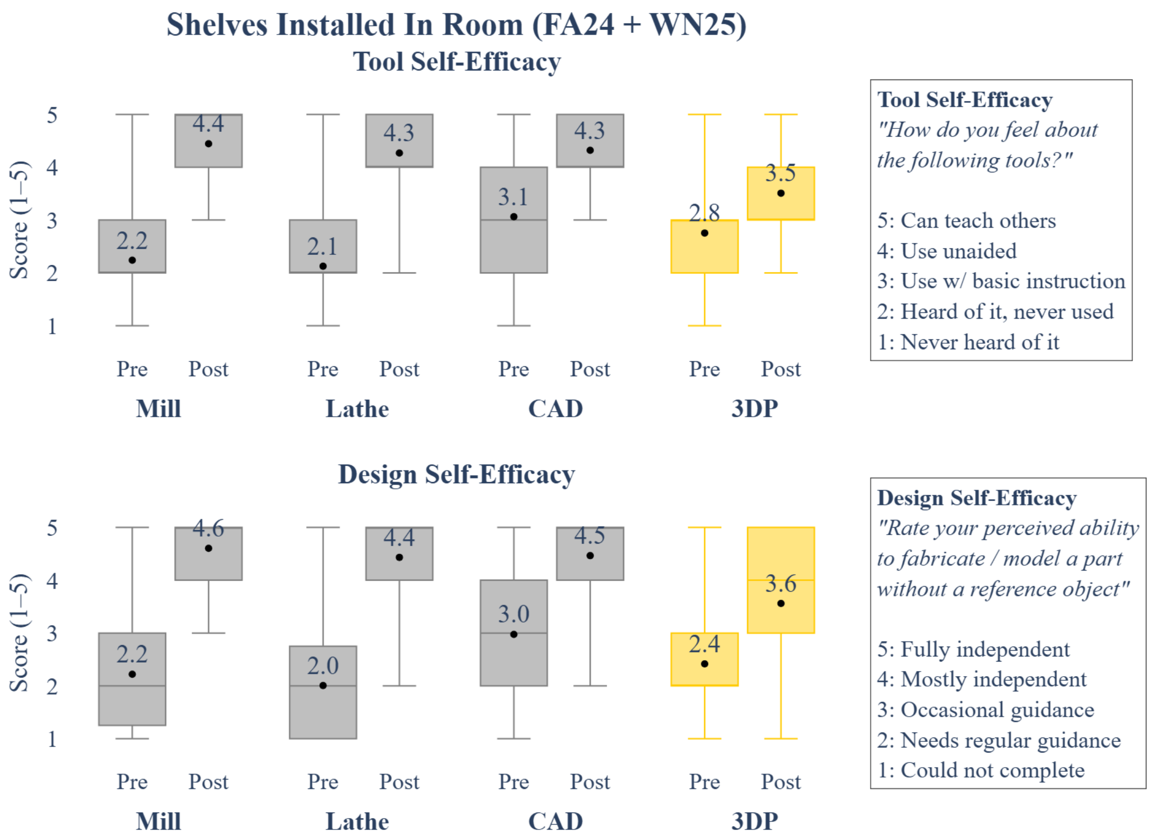

Figure 4. Pre-semester and post-semester self-efficacy scores by domain (tool vs. design) and technology across the Semester of Intervention and Second Semester of Intervention. Refer to the Methods for the Likert scoring definitions.

Analysis of Table 2 revealed substantial gains for traditional fabrication tools following the intervention. Mill self-efficacy improved by 2.21 points (from 2.24 to 4.45), lathe by 2.14 points (from 2.13 to 4.27), and CAD by 1.26 points (from 3.06 to 4.32). Final average scores for these domains approached the maximum, indicating strong student confidence and independence with these tools by the end of the semester.

In contrast, self-efficacy for 3D printing increased less despite starting from a higher baseline. Scores for 3D printing as a tool rose from 2.75 to 3.51, an increase of 0.76 points, and 3D printing design increased from 2.42 to 3.56, an increase of 1.14 points. Although initial averages for 3D printing were higher than for mill and lathe, the magnitude of improvement was smaller, and post-intervention averages remained below those for traditional manufacturing tools and CAD. This disparity suggests students continue to experience lower confidence and mastery in 3D printing technology compared to established fabrication tools, underscoring a need for sustained and targeted support in the curriculum for newer technology domains.

Wilcoxon Signed-Rank Tests revealed statistically significant improvements across all four domains in both tool- and design-related contexts. For the tool-related skills, Mill ($Z = 10.77$, $p < .001$), Lathe ($Z = 10.84$, $p < .001$), CAD ($Z = 9.67$, $p < .001$), and 3D Printing ($Z = 8.65$, $p <$

.001) all showed significant pre-to-post gains. Similarly, within the design-related measures, Mill (Z = 10.60, $p < .001$), Lathe (Z = 10.84, $p < .001$), CAD (Z = 9.80, $p < .001$), and 3D Printing (Z = 8.64, $p < .001$) demonstrated significant improvements. While the 3D Printing intervention was effective in increasing post-intervention scores, the magnitude of change in 3D Printing was smaller than the improvements observed in the traditionally taught domains. Overall, these findings indicate meaningful pre-to-post improvements across all domains, with differences in the extent of change reflecting both domain type (tool vs. design) and relative participant experience.

Despite overall gains, a substantial percentage of students continued to report low self-efficacy in 3D printing after the intervention. Specifically, 18% indicated regular guidance was required for 3D printing design tasks (score of 2), and 4% stated they could not complete such a task (score of 1). For 3D printing as a tool, 17% reported a score of 2, with no students reporting a 1. In contrast, responses of 1 or 2 for traditional tools like mill and lathe were virtually absent post-intervention (Table 3).

Table 3. Low self-efficacy (scores of 1 or 2) reported as percentage of total responses post-semester, Semester of Intervention and Second Semester of Intervention

	Tool				Design			
	Mill	**Lathe**	**CAD**	**3DP**	**CAD**	**3DP**	**Mill**	**Lathe**
2's	0	1	0	27	2	29	0	1
1's	0	0	0	0	0	6	0	0
2's %	0%	1%	0%	17%	1%	18%	0%	1%
1's %	0%	0%	0%	0%	0%	4%	0%	0%

In summary, students self-reported significantly lower self-efficacy in tool usage and design for 3D printing than for CAD, mill, and lathe.

Discussion

This study examined the impact of increased access to 3D printing on robot design teams' utilization of additive manufacturing (AM) and their self-efficacy in both tool operation and design tasks. The intervention consisted of optional 3D printing training and expanded printer access, whereas traditional fabrication tools (mill, lathe, CAD) were already embedded in the curriculum as mandatory individual exercises, with additional graded individual reflective assignments for mill and CAD following Kolb's experiential learning cycle [15]. By situating 3D printing within a context where traditional tools were already structured and supported, we were able to examine the effects of access on engagement and confidence with a newer technology independently of guided practice.

Results indicate that simply increasing access to 3D printing significantly reduced the number of teams reporting no utilization, from 41% in the Pre-Intervention Semester to 11% in the Second Semester of Intervention, and significantly increased moderate utilization, from 22% to 56%.

Low utilization remained stable across semesters, and high utilization did not change substantially, suggesting that access alone may be sufficient to move teams from non-use to moderate engagement, but insufficient to promote high-level adoption.

Self-efficacy patterns mirrored utilization trends. Confidence in traditional tools increased substantially across the intervention period, with mill and lathe tool self-efficacy improving by 2.21 and 2.14 points, respectively, and CAD by 1.26 points. These domains reached near-maximal post-intervention scores, reflecting the combined effects of mandatory exercises and structured experiential learning, which provided repeated practice, feedback, and opportunities for reflection. In contrast, self-efficacy for 3D printing increased more modestly: 3D printing tool confidence rose by 0.76 points and 3D printing design by 1.14 points, with post-intervention averages remaining below those for traditional tools. Notably, 17–18% of students continued to report requiring guidance for 3D printing tasks, and a small subset (4%) reported they felt they could not complete the design task even with assistance. These findings suggest that while access can drive engagement, confidence and mastery for newer AM technologies may require structured practice, feedback, and reflection, as implemented for traditional tools.

Several potential confounders should be considered when interpreting these results. Students had the opportunity to view successful RMPs from prior semesters, which may have served as informal guidance or motivation, contributing to increased 3D printing utilization. Furthermore, exemplary RMPs retained between semesters were completed by moderate or high AM users, potentially biasing subsequent student engagement and confidence. An additional observation is that all high-utilization teams from all three observed semesters included at least one teammate with maximum pre-semester self-efficacy in CAD and 3D printing, highlighting the role of peer expertise in facilitating adoption. Collectively, these factors may have amplified the observed gains in utilization and self-efficacy, suggesting that part of the effect attributed to increased access could instead reflect social learning or exposure to exemplary projects.

Together, these results highlight a distinction between opportunity-driven engagement and structured or scaffolded skill development. The intervention successfully increased moderate engagement with 3D printing, demonstrating that access alone can influence behavior. However, smaller gains in self-efficacy and persistent low-confidence responses emphasize the need for instructional scaffolding to foster deeper mastery and independent capability. For emerging technologies like 3D printing, integrating optional access with guided practice, reflective exercises, or graded assignments may accelerate both utilization and confidence, aligning outcomes more closely with those observed for established tools.

Conclusion

This study directly addresses the question posed by the title: Is access enough? Our findings indicate that increasing access to 3D printing within an ABET-compliant mechanical engineering curriculum can significantly drive engagement. Teams reporting no utilization of additive manufacturing decreased dramatically, and moderate utilization rose substantially over the course of the intervention. These outcomes demonstrate that access alone is sufficient to encourage students to explore and integrate a new technology into their design projects.

However, improvements in self-efficacy were more modest compared with traditional, mandatory fabrication tools such as the mill, lathe, and CAD, which included structured exercises and opportunities for reflection. Students continued to report needing guidance or feeling unable to complete 3D printing tasks independently. These findings indicate that while access can spark engagement, it is not sufficient to achieve mastery or full confidence. Structured practice, feedback, and guided reflection remain critical for building independent competency.

Future work could explore how much scaffolding is necessary in a 3D printing exercise for students to report self-efficacy comparable to mill, lathe, and CAD. For example, a potential activity might guide students step-by-step: designing a part in CAD, exporting and slicing the file for 3D printing, and setting up the machine for fabrication. By adjusting levels of instructor support, oversight, and required documentation, researchers could explore how much structure is needed for students to reach independent proficiency. A companion study testing exactly this question—a brief, individually required FFF exercise implemented in the same course—is reported in [16].

The potential influence of prior exemplary projects and pre-existing moderate/high users suggests that social learning may amplify the effects of access but cannot replace deliberate instructional design. Taken together, the results reinforce a central insight: access is necessary but not sufficient for developing high self-efficacy and deep technical competence. Integrating structured learning experiences is critical for building technical competence and confidence in both established and emerging manufacturing technologies.

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