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From Theory to Practice: A Study on Integrating Makerspaces into Undergraduate Curriculum

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Abstract

This study investigates whether integrating makerspace activities into a formal, credit-bearing course enhances undergraduate students' ability to innovate and engage in a project-based learning (PBL) engineering curriculum. Using a modified Student Assessment of Learning Gains (SALG) instrument that captures key student-relevant competencies, we compared 42 students enrolled in a three-credit Makerspace-based Engineering Design course (treatment group) with 38 students who used the makerspace for other PBL courses (control group). Rigorous statistical analyses reveal that the treatment group achieved moderate to high gains across all measured competencies, with significant differences observed between groups ($p < 0.01$, effect sizes ranging from moderate to high). Preliminary qualitative feedback further supports these findings. We conclude that formal curricular integration of makerspace activities significantly enhances students' innovation and engagement outcomes in project-based learning.

Keywords: *Makerspace Integration; Project-Based Learning; Undergraduate Innovation; Engineering Education; Iterative Design; Entrepreneurial Mindset*

1. Introduction

The rapid evolution of technology and the growing emphasis on experiential learning have challenged traditional higher education pedagogies. Academic makerspaces, collaborative, technology-rich environments, have emerged as transformative platforms that bridge the gap between theoretical instruction and real-world application (Galaleldin et al., 2017; Wilczynski & Stark, 2015; Hoople et al., 2020). These spaces often incorporate maker technologies such as 3D printing and laser cutting, which develop design skills, problem solving, and teamwork in engineering education (Galaleldin et al., 2019). Beyond engineering, makerspaces have also been integrated into courses spanning the arts, business, and the social sciences, thereby supporting multidisciplinary learning experiences (Wilczynski et al., 2017; Berg et al., 2020) and fostering inclusivity (Heintzman, 2018).

Research indicates that effective curricular integration can positively impact student engagement, teamwork, and innovation skills (Nilsson, 2012; Berg et al., 2020). Additionally, structured makerspace experiences help address organizational and didactic challenges, ensuring that students not only gain hands-on skills but also develop an entrepreneurial mindset (Stephanie Gillespie et al., n.d.; Bonnie H. Ferri et al., 2017). Despite the benefits of extracurricular makerspace activities, few studies have systematically integrated these experiences into formal, for-credit curricula. Research suggests that structured integration can boost student engagement, teamwork, and innovation skills (Nilsson, 2012; Sandtrø et al., 2020), while also cultivating an entrepreneurial mindset (Gillespie et al., n.d.; Ferri et al., 2017).

This study examines an Engineering Design course called Innovation Through Making, an eight-week, three-credit offering that integrates makerspace activities within a PBL framework at Worcester Polytechnic Institute (WPI). The course uses a blended learning approach that includes flipped classroom lectures, active learning sessions, and dedicated makerspace workshops, culminating in a Prototype Showcase that emphasizes innovation, sustainability, and real-world impact. By comparing learning gains between course participants and a control group with unstructured makerspace access, we seek to determine how formal curricular integration improves undergraduate innovation and engagement outcomes.

2. Research Methods

2.1. Course Description:

Innovation Through Making is an engineering design sciences elective offered as a new experimental course at WPI. Learning outcomes target five competencies: tool proficiency, iterative design, creative problem solving, collaboration, and entrepreneurial mindset. Table 1 summarizes the core makerspace activities.

Approximately 50 % of class time occurs in the makerspace; the remainder uses flipped-classroom discussions and design reviews to link theory to practice.

2.2. Group Selection

A total of 42 undergraduate students enrolled in the Makerspace course served as the treatment group. This was collected over three course offerings stretching a three-year period. Demographic data (including major, academic year, and gender) were collected to study any dependent descriptive factors. To isolate the impact of formal curricular integration, a control group of 38 students was selected from those concurrently enrolled in two other project-based

Table 1. Weekly Makerspace Activities and Alignment to Competencies

Week	Activity	Competency Alignment*
1	"Maker Passport" safety & intro workshop; simple laser-cut key-tag	TP
2	Low-fidelity cardboard prototype of a kinetic toy	ID, CPS
3	CAD & 3-D-print challenge	TP, ID
4	Mid-term peer critique & design-iteration log	CE, CPS
5	Electronics integration: Circuits	TP, CPS
6	Failure-reflection journal & redesign	EM, ID
7	High-fidelity prototype using mixed media	TP, ID, CE
8	Prototype Showcase with industry judges	EM, CE

*TP = Tool Proficiency; ID = Iterative Design; CPS = Creative Problem Solving;
CE = Collaborative Engagement; EM = Entrepreneurial Mindset.

undergraduate courses at the same institution. Although these students had access to the same makerspace facilities for their projects, they did not receive, nor were they required, to use a dedicated makerspace curriculum.

2.3. Data Collection Instruments and Procedure

Data were collected using a modified version of the Student Assessment of Learning Gains (SALG) instrument, administered to both groups at the beginning (pre-course) and the end (post-course) of the term. The SALG is a validated survey that asks students how much specific aspects of a course helped their learning (Vogt et al., 2005). We adapted item stems to target makerspace competencies; each sub-scale exhibited high internal consistency (Cronbach's $\alpha = 0.86–0.91$). The SALG was tailored to capture several student-relevant competencies, which are defined as follows:

- **Tool Proficiency:** The student's self-assessed ability to effectively operate makerspace technologies (e.g., 3D printers, laser cutters) and other technical equipment.
- **Iterative Design & Prototyping:** The capacity to apply design thinking and engage in successive cycles of prototyping, evaluation, and refinement to develop functional and innovative solutions.
- **Creative Problem Solving:** The ability to generate and implement innovative solutions for complex, real-world challenges by thinking outside conventional frameworks.
- **Collaborative Engagement:** The effectiveness with which students work in teams, share ideas, and leverage diverse perspectives to improve project outcomes.

- **Entrepreneurial Mindset (Risk-Taking):** The willingness to embrace uncertainty and learn from failure, reflecting a proactive approach to exploring novel ideas and opportunities.

All control-group students completed the same pre-course and post-course SALG surveys (administered at the start and conclusion of their respective courses), enabling a direct comparison of learning gains. Background checks ensured that no control-group participant was simultaneously enrolled in the course, thus maintaining a clear separation of experiences.

2.4. Data Analysis

For data analysis, paired t-tests were used to assess within-group changes in SALG scores from pre- to post-course. An analysis of covariance (ANCOVA) was then performed to compare post-course outcomes between the treatment and control groups while controlling for baseline differences. Reliability analyses (e.g., Cronbach's alpha) were conducted to confirm the internal consistency of the modified SALG subscales. Subgroup analyses were also performed to explore potential differences in gains based on major, academic year, or gender. This approach enabled a rigorous evaluation of the impact of formal makerspace curricular integration on undergraduate innovation and engagement within a project-based learning framework. Demographic comparisons were also conducted to confirm that observed differences were not attributable to variations in gender, major, or academic year.

3. Results

3.1. Participant Demographics

Table 2 summarizes the demographic profile of both groups. No statistically significant differences in major distribution, academic year, or gender were observed, ensuring that differences in learning gains are attributable to the course design rather than demographic variation.

Table 2. Demographic Overview of Treatment and Control Groups

	n	% Engineering	% Non-Engineering	Avg. Academic Year	% Female
Treatment (Course)	42	60%	40%	2.8 (soph–senior)	40.5%
Control (2 PBL Courses)	38	62%	38%	2.9 (soph–senior)	42.1%

3.2. SALG Results

Table 3 summarizes the pre-course and post-course SALG scores (M ± SD) for the five domains. Each item was rated on a 5-point Likert scale (1 = "Very Low" to 5 = "Very High"). Within-group paired t-tests showed significant improvements in all domains for both groups; however, ANCOVA, controlling for pre-course scores, revealed that the treatment group's post-course scores were significantly higher than those of the control group ($p < 0.01$).

Table 3. Pre-Post SALG Mean Scores and Statistical Analyses (n=42 Treatment, n=38 Control)

Domain	Group	Pre (M ± SD)	Post (M ± SD)	Paired t-test (p)	ANCOVA (Post Scores, Treatment vs. Control)
Tool Proficiency	Treatment	2.75 ± 0.75	4.10 ± 0.60	< 0.001	< 0.001
	Control	2.76 ± 0.80	3.30 ± 0.70	0.012	-
Iterative Design & Prototyping	Treatment	2.80 ± 0.70	4.05 ± 0.65	< 0.001	< 0.001
	Control	2.69 ± 0.65	3.35 ± 0.68	0.018	-
Creative Problem Solving	Treatment	2.90 ± 0.66	4.20 ± 0.55	< 0.001	< 0.001
	Control	3.00 ± 0.60	3.50 ± 0.60	0.011	-
Collaborative Engagement	Treatment	3.10 ± 0.72	4.30 ± 0.50	< 0.001	0.002
	Control	3.15 ± 0.70	3.65 ± 0.68	0.015	-
Entrepreneurial Mindset	Treatment	2.70 ± 0.80	3.95 ± 0.68	< 0.001	0.003
	Control	2.65 ± 0.75	3.20 ± 0.72	0.027	-

Both the treatment and control groups exhibited statistically significant improvements from pre- to post-course across all domains ($p < 0.05$). Post-course scores in the treatment group were significantly higher than those in the control group for all domains ($p < 0.01$ for most comparisons). Effect sizes ranged from moderate to high (Cohen's d ≈ 0.6 to 0.9), indicating that formal, credit-bearing makerspace integration provided a substantive advantage.

Tool Proficiency, Iterative Design & Prototyping, and Creative Problem Solving showed the most pronounced gains in the treatment group. Entrepreneurial Mindset (risk-taking) also demonstrated a notable jump, suggesting that students became more comfortable experimenting with novel ideas and learning from failures.

The bar graph in Figure 1 visually compares mean pre-to-post gain scores for each competency, clearly illustrating the larger improvements achieved by students in the structured makerspace course (treatment) versus those with unstructured makerspace access (control).

3.3. Interpretation of Findings

The SALG results strongly indicate that a structured, for-credit makerspace course yields moderate to high gains in key innovation-related competencies. Notably, while the control group also showed improvements, likely due to the inherent value of PBL tasks, these gains were smaller, implying that unstructured makerspace access alone may be insufficient to maximize students' creative and entrepreneurial potential.

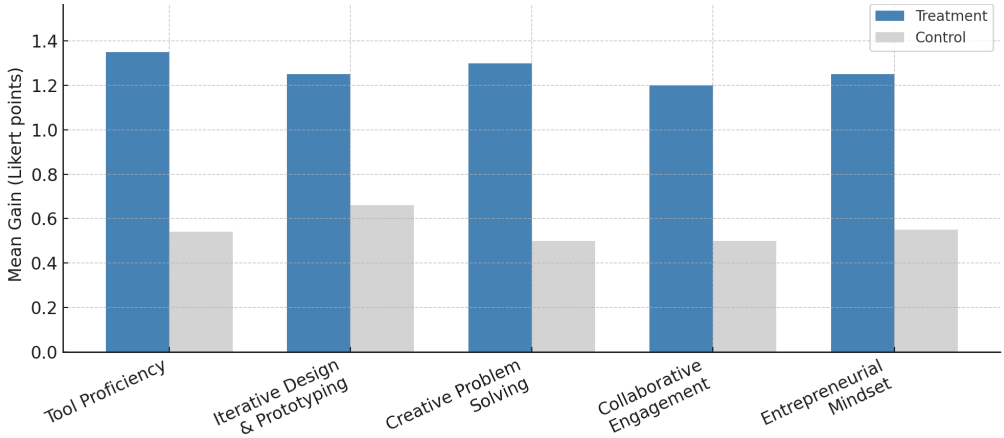

Figure 1. Mean SALG Gain Scores (± SE) by Competency

Tool Proficiency and Iterative Design improvements suggest that repeated, guided exposure to emerging technologies within an academic context fosters deeper mastery. This outcome is consistent with prior research emphasizing the importance of structured didactic approaches in maker education (Kaar & Stary, 2019). Meanwhile, the jump in Creative Problem Solving aligns with the notion that makerspaces can act as catalysts for design thinking and real-world experimentation (Wilczynski et al., 2016; Mohamed Galaleldin et al., 2019). These results also extend findings (Sakkal & Harlan,2024) by demonstrating that credit weighting and explicit alignment to course outcomes magnify learning gains.

The robust increases in Collaborative Engagement and Entrepreneurial Mindset reflect students' evolving attitudes toward teamwork, iterative risk-taking, and embracing failure as a learning opportunity (B. Robinson et al., 2020; Sakkal & Harlan, 2024). This shift is particularly relevant in engineering contexts where cross-functional collaboration and innovation drive project success (Nilsson, 2012; Sandtrø et al., 2020).

Limitations include modest sample sizes, which may limit the generalizability of these findings, and self-selection bias, as students opting to enroll in a makerspace-focused course may already possess higher interest in hands-on learning. Additionally, external factors, such as teaching styles in the control-group courses, can variably influence outcomes. Nonetheless, the large effect sizes and consistency across multiple domains lend strong support to the efficacy of the course design.

4. Conclusion

In summary, our study demonstrates that embedding makerspace activities into a formal, for-credit course significantly improves undergraduate students' innovation and engagement within a project-based learning curriculum. The treatment group showed moderate to high gains in competencies such as tool proficiency, iterative design, creative problem solving, collaborative engagement, and an entrepreneurial mindset, gains that were statistically and practically significant compared to the control group. These findings suggest that structured curricular integration of makerspace resources empowers students with the skills and confidence needed to address complex, real-world challenges. Although sample sizes were modest and self-selection bias may be present, the consistency of the results and the robust effect sizes indicate that this approach holds substantial promise. Future research should build on these findings with larger samples and deeper qualitative investigations to further elucidate the transformative impact of makerspaces on project-based learning.

Acknowledgements

We gratefully acknowledge that initial findings from an earlier phase of this research were presented at a previous conference (Anand et. al, 2024). The present manuscript extends that work by adding a third course offering, doubling the sample size, introducing a matched control group, employing a revised SALG instrument with makerspace-specific subscales (α = .86–.91), and providing full effect-size analyses. No text, tables, or figures are reused verbatim; all overlapping data are re-analyzed in aggregate. We also thank VentureWell for their financial support, which contributed to the development of the course.

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