A Cost-Effective Hands-On Learning Kit for Enhancing Engagement and Design Skills

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Abstract
This Work in Progress paper examines the classroom implementation of a low-cost 3D printed learning kit designed to enhance CAD proficiency, engagement, problem solving, and application of mechanical design concepts. The learning kit supports measurement-based modeling, material assignment, mass property verification, open-ended redesign, and optional interdisciplinary exploration. This study evaluates how use of the learning kit influences engagement, perceived CAD learning, confidence, and performance differentiation. Evidence includes an eleven item five point Likert survey, qualitative student reflections, learning kit scores, CSWA outcomes, and comparison of final grade distributions between semesters with and without the learning kit. Findings indicate increased engagement, positive perceived learning gains, and meaningful differentiation in performance without evidence of grade inflation. The paper also discusses logistical considerations, collaboration dynamics, and future refinements.

1. Introduction

Hands-on learning is widely emphasized in engineering design education because it improves student engagement, persistence, and development of practical skills [1]. However, implementing meaningful physical learning experiences is often constrained by cost, access to equipment, and scalability, leading many courses to rely on paper-based or purely digital exercises that do not reflect real-world measurement, tolerancing, or design iteration.

Research on first-year engineering education shows that integrated curricula improve conceptual understanding and student retention by connecting multiple skills within coherent learning experiences [2], [3]. These findings motivate instructional approaches that link CAD, measurement, and physical system behavior rather than treating them as isolated topics.

To address these needs, a low-cost 3D printed mechanical learning kit was developed for use in a CAD-focused design course. The kit and its instructional rationale were previously introduced at the ASEE FYEE 2025 Conference [4]. The present Work in Progress study extends that work by evaluating the learning kit during classroom implementation and examining its effects on student engagement, perceived learning, and course performance.

The learning kit was designed to support measurement-based modeling and CAD accuracy through interaction with real components [5], while also encouraging redesign, iteration, and ownership of design work. This study is guided by the research question: How does a hands-on learning kit influence CAD skill development and classroom engagement? Early findings are presented to evaluate feasibility and inform continued refinement of a cost-effective, scalable instructional tool.

2. Course Context and Learning Kit Description

The learning kit was implemented in MEE1117, Fundamentals of Mechanical Engineering Design, at Temple University. The course introduces students to engineering graphics, technical drawing, hand sketching, and 3D modeling in SolidWorks. Throughout the semester, students complete a sequence of assignments and projects intended to develop both visual communication skills and solid modeling proficiency.

A central component of the assessment structure is the Certified SolidWorks Associate (CSWA) exam [6]. The CSWA is an industry recognized credential that evaluates fundamental skills in SolidWorks, including sketching, feature creation, assemblies, and mass property calculations. In MEE1117, the CSWA is administered in two parts, and each part contributes 20% to the final course grade, for a combined weight of 40%. Students receive structured preparation through practice exams and targeted assignments and are allowed two attempts to complete the certification. Because the CSWA carries substantial weight, overall course grades are strongly influenced by certification performance. The learning kit was therefore designed to support the same core competencies evaluated by the CSWA, such as measurement, modeling accuracy, material assignment, and mass property interpretation, while also emphasizing engagement, collaboration, and design thinking.

The learning kit consists of a small mechanical assembly with five unique components that can be disassembled, measured, modeled, and reconfigured. The parts include features that require careful attention to geometry, dimensioning, and tolerances, making them suitable for both measurement exercises and CAD reconstruction. All components were fabricated using additive manufacturing. Selected parts were printed using Fused Deposition Modeling (FDM) with typical dimensional variation on the order of ±0.5%. Other parts were produced using Stereolithography (SLA) with tighter tolerances around ±0.1%. These differences in fabrication method introduce realistic manufacturing variation and encourage students to think in terms of acceptable error ranges rather than expecting exact nominal values. For grading of mass property calculations, a 5% allowable error margin was used to account for this variation.

The approximate cost of each complete learning kit is about 15 USD, including materials and printing. A detailed cost breakdown and list of materials are provided in [4]. This low cost makes it feasible to deploy kits across multiple course sections and to reuse them in future semesters. Components are sufficiently robust for repeated handling, and any damaged parts can be reprinted with modest effort. The kit geometry was created in SolidWorks and then exported for 3D printing. Design choices were guided by instructional goals, including the incorporation of features that require different measurement strategies, thickness variations that influence mass, and assembly relationships that highlight fit and alignment. These characteristics make the learning kit suitable for the structured CAD measurement assignment as well as the open-ended redesign activities described in later sections.

3. Research Methods

This Work in Progress study examines how the learning kit influenced engagement, perceived CAD learning, confidence, and course performance. Data were collected through a combination of survey responses, course assessment records, and comparative grade analysis between semesters with and without the learning kit.

Eighteen students completed the survey out of seventy nine enrolled, resulting in a 22.8% response rate. Participation was voluntary and did not affect course grades. Survey responses were identifiable to allow comparison with course outcomes but were reviewed only within the instructional team. Respondents were primarily students performing at the highest and lowest grade levels, which suggests participation may have been driven by strong personal investment in the course, either through success or concern.

Students completed an eleven item Likert scale survey that included statements related to engagement, motivation, learning effectiveness, confidence using SolidWorks, relevance to real mechanical systems, and collaboration. Responses were collected on a five point scale ranging from Strongly Disagree to Strongly Agree. Open-ended questions allowed students to describe helpful aspects of the learning kit, challenges encountered, and recommendations for improvement.

In addition to perception-based data, course performance metrics were examined to provide complementary insight. These included learning kit grades, final course grades, and CSWA certification outcomes for both survey participants and the full class. To explore whether introduction of the learning kit corresponded to changes in overall course outcomes, final letter grade distributions from Fall 2024 (without the learning kit) and Fall 2025 (with the learning kit) were compared. Only sections with comparable scheduling and structure were included to maintain fairness. A chi square test of independence was used to evaluate whether semester and final grade distribution were statistically associated. Assumptions related to expected cell frequency were satisfied for this analysis. Together, these methods provide multiple perspectives on instructional impact, including student perceptions, observed performance differentiation, and stability of overall course outcomes.

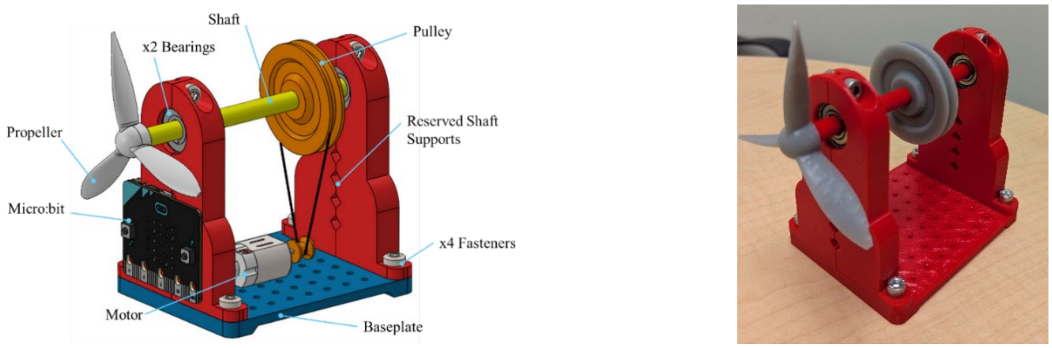

Figure 1 Design of the learning kit and its components (left), and the 3D-printed, assembled version of the kit (right).

4. Results and Discussion

This section presents the preliminary results of implementing the learning kit and discusses their implications for student performance and engagement. Because this work represents an early stage evaluation, results and interpretation are presented together to emphasize observed trends rather than definitive conclusions.

4.1 Grade Distribution and Course Performance

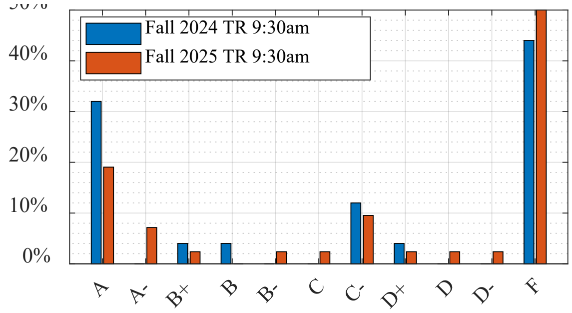

Figure 2 Comparison of final grade distributions in Fall 2024 and Fall 2025.

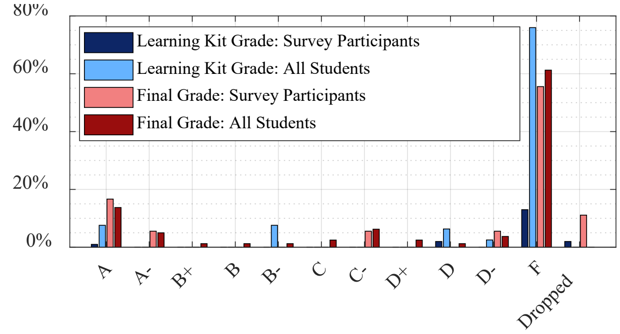

Figure 3 Learning kit grade and final course grade distributions for survey participants and all students.

Figure 2 compares final grade distributions between the semester without the learning kit (Fall 2024) and the semester with the learning kit (Fall 2025). Overall pass and fail rates are similar across semesters; however, the learning kit semester exhibits a more even distribution across intermediate grade categories, with reduced concentration at the highest and lowest outcomes.
A chi square test was conducted to examine whether grade distributions differed between semesters. The test indicated no statistically significant difference ($\chi^2 = 7.43$, df = 10, $p = 0.684$).
To further examine grade patterns within the learning kit semester, Figure 3 presents learning kit grade and final course grade distributions for both survey participants and the full class. Learning kit grades show a broader spread across intermediate categories compared to final course grades, particularly among survey participants. This suggests that performance on learning kit activities may reflect incremental learning gains that are not fully captured by aggregate final course grades.

4.2 CSWA Performance Comparison

CSWA exam performance was examined as an external measure of CAD competency (Fig 4). Pass rates for both CSWA Part 1 and Part 2 were compared across semesters. While pass rates varied between years, the overall CSWA success rate remained comparable. This aligns with the course grade analysis, indicating that the introduction of the learning kit did not immediately translate into higher standardized exam pass rates.

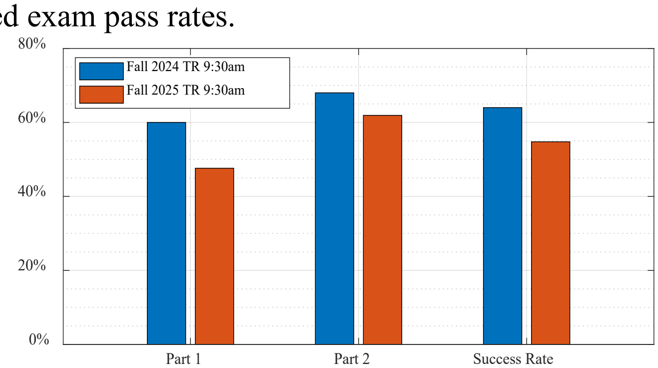

Figure 4 CSWA Passing Percentages by Exam Part, Comparison of Fall 2024 and Fall 2025

However, given that the CSWA exam accounts for a substantial portion of the final course grade, stable CSWA outcomes alongside a more balanced grade distribution may suggest that the learning kit helps students develop practical skills and conceptual understanding without disproportionately advantaging or disadvantaging exam performance. This balance is important in courses where certification exams significantly influence final grades.

4.3 Student Perception and Engagement Survey Results

Survey responses (Fig. 5) related to student engagement and perceived learning benefits consistently trended toward agreement or strong agreement. A majority of students reported feeling more engaged when using the learning kit compared to traditional assignments. Neutral and disagree responses were present but represented a smaller proportion of the total responses. These perception based results support the qualitative intent of the learning kit, which emphasizes hands on interaction, peer collaboration, and real world measurement and modeling tasks. While self reported engagement does not directly equate to improved performance, increased engagement is widely associated with persistence and deeper learning, particularly in skill based engineering courses.

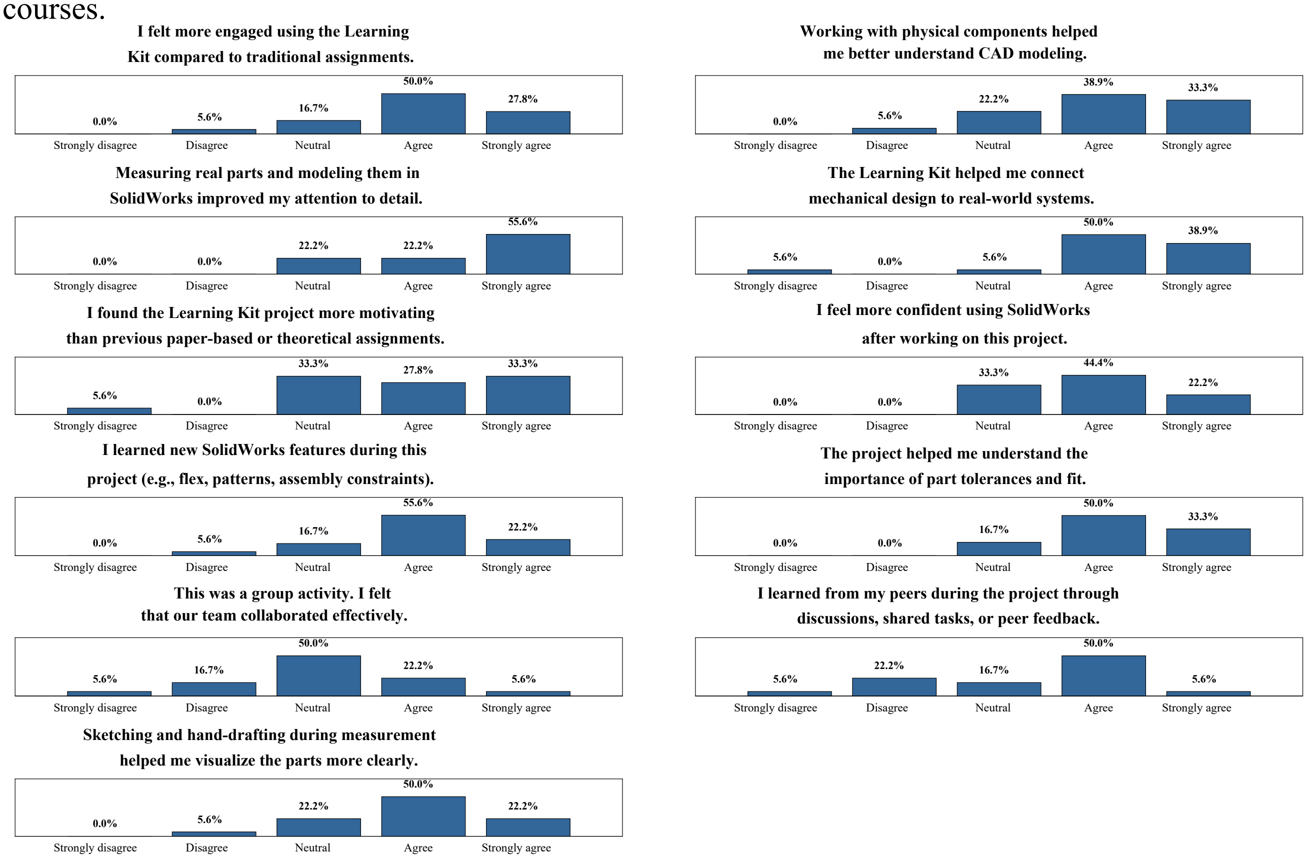

Figure 5 Student survey responses on learning kit engagement and effectiveness

4.1 Interpretation and Instructional Implications

Overall, the learning kit appears to influence the learning process more than final grades or exam pass rates. The shift toward intermediate outcomes and positive student feedback suggest steadier progress through course material. These early results support continued use and refinement of the kit, with additional semesters needed to evaluate longer-term effects.

5. Future Work and Conclusion

This Work in Progress study evaluated a hands-on learning kit for CAD instruction. While grades and CSWA pass rates did not change significantly, student feedback was positive and grade patterns suggest potential incremental benefits.

Future work will add more semesters of data, refine assessment alignment, and better control for cohort differences. Continued iteration will clarify the kit's longer-term impact on learning and engagement.

Acknowledgements

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