Flipped Classroom and Collaborative Learning in Tool Design Education for Mechanical Engineering Technology

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Abstract

Traditional Tool Design courses often rely on passive lectures and individual assignments, which can limit engagement and creativity, particularly for Mechanical Engineering Technology students at Hispanic-Serving Institutions (HSIs), where diverse student backgrounds necessitate pedagogical approaches that support varying learning styles. This paper introduces a flipped classroom and Computer-Supported Collaborative Learning (CSCL) model aimed at fostering practical skills and teamwork in Tool Design education. In this model, foundational concepts—such as jig and fixture design—are delivered through video lectures, interactive CAD tutorials, and quizzes, enabling students to learn at their own pace. Out-of-class activities reinforce theoretical knowledge by allowing students to explore pre-built models and solve design-related questions. Class time is dedicated to collaborative projects where students use cloud-based CAD tools to design and optimize manufacturing fixtures. Instructors act as facilitators, providing real-time feedback and guidance, simulating the collaborative nature of modern engineering workplaces. The model's effectiveness is evaluated using peer reviews, design challenges, final group projects, surveys, and reflections. Initial results demonstrate increased participation, enhanced problem-solving skills, and a deeper understanding of tool design concepts. This paper outlines a scalable approach to Tool Design education that prepares students for industry challenges while promoting collaboration and hands-on learning.

Keywords: Tool Design, Flipped Classroom, Collaborative Learning, Cloud-based CAD

1. Introduction

1.1. Brief Review of Flipped Classroom Applications in Engineering Education

The flipped classroom model has emerged as a transformative approach in engineering education, addressing limitations of traditional teaching methods[1]. By shifting theoretical content delivery to pre-class activities and dedicating class time to active learning, this model fosters deeper engagement, better conceptual understanding, and enhanced collaborative skills. Studies have shown its effectiveness across various engineering disciplines, including mechanical engineering courses such as statics[2], rigid body dynamics[3], and thermodynamics [4]. Bishop and Verleger highlighted that flipped classrooms promote active learning, enabling students to tackle problem-solving and design challenges during class while leveraging pre-class resources like video lectures and interactive tutorials [5, 6].

Jensen et al. found that students in flipped engineering courses consistently outperformed their peers in traditional classrooms on assessments and projects [7,8]. This success was attributed to the integration of multimedia tools and collaborative activities, which improved knowledge retention and its application to real-world problems. In CAD and design courses, flipped classrooms facilitated team-based design projects that mirrored industry practices, helping students develop both technical expertise and essential soft skills[9].

Flipped classrooms have also shown particular promise in diverse educational environments, such as Hispanic-Serving Institutions (HSIs). Their active and inclusive nature accommodates varied learning styles and backgrounds, promoting equity in learning outcomes. For instance, Lo and Hew reported that flipped classrooms significantly enhanced student confidence and collaboration in engineering courses at institutions serving underrepresented groups[10].

However, the success of this model relies heavily on careful implementation. high-quality pre-class materials, engaging in-class activities, and the use of technology, such as cloud-based collaborative tools [11] and virtual laboratories[12], are critical for its effectiveness. When thoughtfully applied to courses like tool design, where hands-on learning and collaboration are essential, the flipped classroom model has the potential to revolutionize engineering education[13].

1.2. Balancing Traditional and Modern Pedagogies

Traditional teaching methods in Tool Design courses, while effective for foundational theoretical learning, often emphasize rote memorization and isolated problem-solving, limiting creativity and teamwork development. The rigid separation of theory from practical application further hinders students' ability to connect abstract concepts to real-world scenarios, particularly in diverse settings like HSIs, where traditional approaches may fail to engage all learners equitably.

The flipped classroom model addresses these challenges by shifting theoretical instruction to multimedia-based, out-of-class activities, such as video lectures, interactive CAD tutorials, and self-paced quizzes, allowing students to learn at their own pace. In-class sessions focus on collaborative, project-based learning, where students use cloud-based CAD tools to design and optimize jigs and fixtures, mimicking real-world engineering practices. Instructors act as facilitators, providing real-time feedback and guidance on complex design challenges.

This approach bridges the gap between theory and practice, fostering creativity and equipping students with essential teamwork and problem-solving skills for modern engineering careers. Figure 1 illustrates the advantages of the flipped classroom model, demonstrating its contribution to enhanced student performance and innovative outcomes in tool design education.

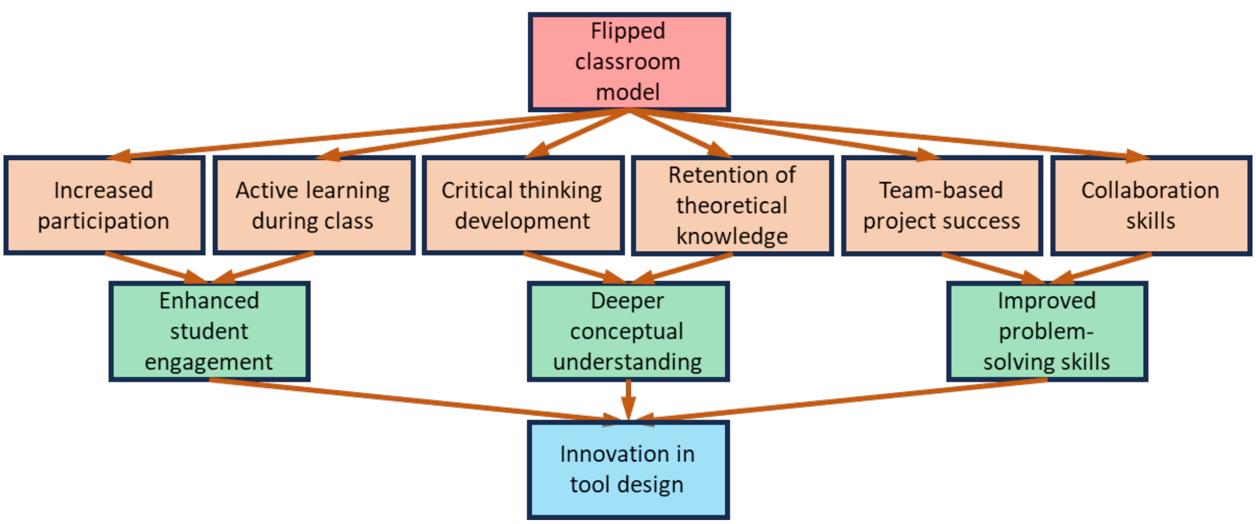


Figure 1: Representation of flipped classroom benefits in tool design class

2. Addressing Challenges in Tool Design Education for Mechanical Engineering Technology

2.1. Differentiating Mechanical Engineering and Mechanical Engineering Technology

Mechanical Engineering (ME) and Mechanical Engineering Technology (MET) programs differ in their approach to education and skill development. ME programs emphasize theoretical analysis, mathematical modeling, and system design, preparing graduates to develop and refine complex engineering solutions through simulation and analytical techniques. In contrast, MET programs focus on the practical application of engineering principles, emphasizing hands-on learning, project-based education, and industry-aligned skill development. MET graduates are trained to work directly with manufacturing processes, system optimization, and real-world problem-solving, making them highly valuable in applied engineering roles[14,15].

Given the applied nature of MET education, traditional lecture-based instruction alone may not fully support the development of the hands-on competencies and collaborative problem-solving skills required in the industry. Instead, active learning strategies—such as the flipped classroom and Computer-Supported Collaborative Learning (CSCL)—are particularly well suited for MET students. These approaches provide structured opportunities for students to engage in real-world design tasks, collaborate on complex engineering projects, and develop proficiency in industry-standard tools such as CAD software and digital manufacturing platforms.

In courses like Tool Design, where teamwork and iterative problem-solving are critical, integrating a flipped classroom model allows students to absorb foundational concepts before class, enabling instructor-led, hands-on project work during in-person sessions. Similarly, CSCL facilitates cloud-based collaboration, mimicking modern engineering environments where team-based virtual design and real-time feedback are essential[16,17,18]. By aligning instructional strategies with the competencies required in applied engineering fields, these pedagogical methods enhance student engagement, strengthen technical proficiency, and better prepare MET graduates for workforce challenges[19].

2.2. Curriculum Integration: Bridging Theory and Practice

A typical knowledge structure is illustrated in Figure 2, showing the hierarchical organization of key disciplines and their subcategories in Mechanical Engineering Technology. This structure highlights the interconnected areas of Math, Science, Engineering, and Technology, providing a clear overview of foundational and applied knowledge essential to the field. Besides, this hierarchical curriculum structure positions Tool Design as a pivotal mid-level course, typically taken during the fourth or fifth semester. At this stage, students are expected to have foundational knowledge in key areas such as calculus, linear algebra, materials, mechanics, dynamics, computer-aided drawing, and machining. These prerequisites establish the baseline for understanding the multifaceted nature of tool design, which integrates principles from mathematics, science, engineering, and technology[20].

Tool Design bridges foundational and advanced courses, challenging students to synthesize prior knowledge through hands-on, project-based work. However, variability in knowledge retention and traditional pedagogies often limit collaboration and the application of theoretical concepts to real-world challenges. These gaps are especially pronounced in areas like machining, tooling, and programming, where practical skills and creative problem-solving are essential.

The flipped classroom model addresses these challenges by shifting foundational content delivery to video lectures, interactive CAD tutorials, and self-paced quizzes, enabling students to build confidence before class. In-class sessions emphasize collaborative projects using cloud-based CAD tools, fostering interdisciplinary teamwork and reinforcing theoretical knowledge. Hands-on activities, such as machining and soldering, further bridge coursework and industry demands.

This approach, supported by instructor facilitation and real-time feedback, aligns curriculum design with practical applications and equips students with the skills needed to meet the dynamic demands of modern engineering.

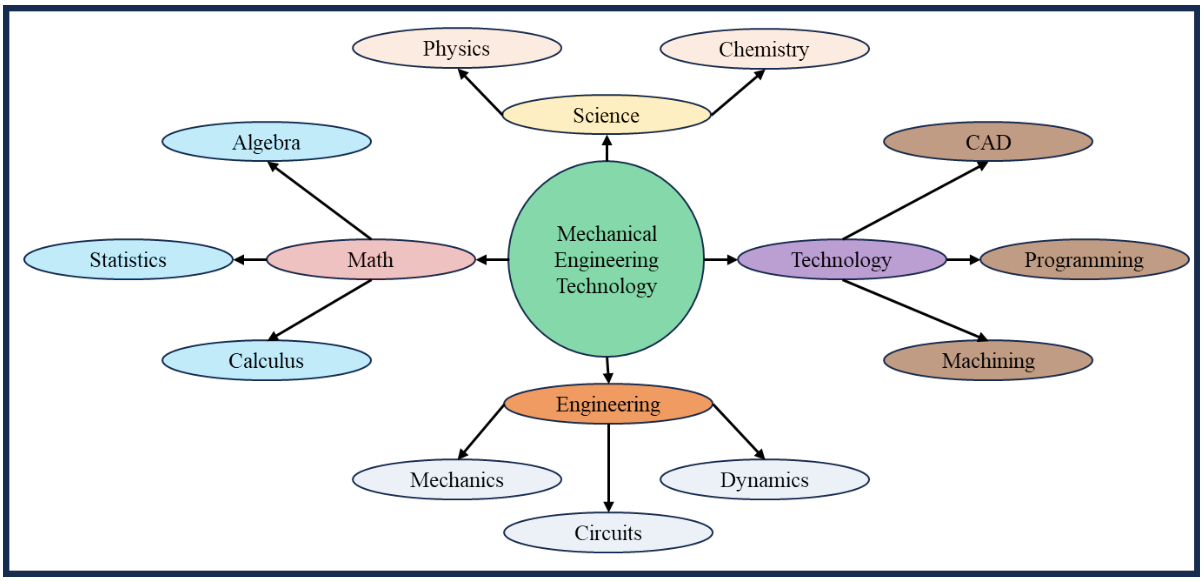


Figure 2: Briefing to hierarchical knowledge structure in mechanical engineering technology

2.3. Advancing Student Success with Innovative Pedagogies

Promoting student success in Tool Design education requires innovative teaching methods rooted in key pedagogical principles, including collaboration, active participation, and continuous evaluation. The flipped classroom model embodies these principles by fostering teamwork, aligning activities with industry-relevant outcomes, and accommodating diverse learning styles through multimedia resources and hands-on projects [21].

This approach emphasizes real-world applications, engaging students in project-based tasks and in-class challenges that deepen theoretical understanding while developing practical skills. Instructors facilitate learning by guiding problem-solving exercises, promoting critical thinking and adaptability.

Assessment tools such as peer reviews, design challenges, and final projects provide ongoing feedback, ensuring students master technical skills while excelling in creativity and teamwork. By integrating these strategies, the flipped classroom creates an inclusive, engaging, and outcome-driven environment, addressing traditional pedagogical limitations and preparing students for academic and professional success [22,23].

3. Implementation of Flipped Classroom for Tool Design Education

3.1. Course overview and student demographics

The Tool Design course offers a comprehensive introduction to the fundamentals of tool design, emphasizing jig and fixture design principles. Students explore topics such as the objectives and economic considerations of tool design, tooling materials, work-holding principles, and the design and operation of jigs, fixtures, and dies. The curriculum also covers power presses, metal cutting, forming, and drawing techniques, providing a practical understanding of these processes[24].

Through hands-on 3D CAD modeling and laboratory sessions, students gain practical experience designing and creating detailed tool drawings. The course equips students with the knowledge to analyze part data, determine appropriate tool designs, specify locating and clamping methods, and understand the principles of metal stamping and sheet metal design. By integrating theoretical and practical learning, this course prepares students to address real-world manufacturing challenges effectively.

The flipped classroom implementation involved two sections of a Tool Design course, each initially comprising 20 students. The student demographic primarily consisted of fourth- and fifth-semester students, with approximately 20% holding full-time jobs and 85% engaged in part-time employment. Most students demonstrated strong hands-on abilities but faced challenges with analytical reasoning, a skill identified as a key area for improvement.

A significant proportion of the students (80%) were first-generation college attendees, with Latino students representing 65% of the total enrollment. This cohort brought a wealth of diverse experiences, balancing academic responsibilities with external commitments such as part-time or full-time employment. Many students demonstrated strong hands-on skills and practical problem-solving abilities, reflecting the applied nature of Mechanical Engineering Technology education. Recognizing the varying educational backgrounds and potential challenges faced by first-generation students, the course was designed to provide an inclusive and supportive environment that fosters engagement, confidence, and professional growth. The flipped classroom and collaborative learning approach aimed to bridge gaps in prior knowledge, promote teamwork, and align instructional strategies with industry-relevant skill development..

As the instructor, my role extended beyond delivering theoretical content. I aimed to create an engaging and welcoming classroom atmosphere, utilizing a blend of innovative teaching methods and pedagogical strategies to ensure all students could achieve.

3.2. Integrating flipped classroom and CSCL methodologies

The implementation of the flipped classroom and CSCL model in Tool Design education was designed to enhance both individual and team-based learning while aligning with modern industry workflows. To evaluate the effectiveness of this pedagogical approach, two sections of the course were analyzed: one followed traditional lecture-based instruction throughout the semester as a control group, while the other incorporated the flipped classroom model in the second half of the semester, after the midterm. This experimental design allowed for both horizontal (between sections) and vertical (within the same class) comparisons, providing insights into the impact of active and collaborative learning techniques.

The flipped classroom model shifted theoretical instruction to multimedia-based, out-of-class activities, ensuring that students could engage with foundational concepts at their own pace before in-class sessions. Students accessed pre-recorded video lectures covering jig and fixture design, supporting and locating principles, and clamping methods. Interactive CAD tutorials reinforced these concepts, and self-paced quizzes provided an additional layer of assessment to confirm comprehension. This structure allowed for flexibility, particularly for students balancing part-time or full-time employment, while ensuring consistent knowledge acquisition before transitioning to hands-on application in class.

In-class sessions focused on collaborative, project-based learning using cloud-based CAD tools such as AutoCAD Inventor and Fusion 360 [25], which facilitated both in-person and remote teamwork. These platforms enabled students to work synchronously on team-based design projects, receive real-time instructor and peer feedback, and iteratively refine their designs [26,27]. The collaborative process was centered around the Fusion Team Hub, which functioned as a centralized digital workspace for managing project data, tracking design modifications, and organizing team contributions. Students used AutoCAD's "Shared Views" feature to review models during in-person sessions, allowing for immediate critiques and iterative adjustments.

For remote collaboration, Fusion 360's web client played a crucial role in enabling students to edit models, manage project milestones, and track version control in a cloud-based environment. The platform's built-in features allowed teams to maintain design history logs, compare previous iterations, and revert to earlier versions when necessary. To ensure data security and facilitate external review, secure links were used for controlled project sharing, allowing instructors and industry professionals to provide feedback without modifying the original design files.

Beyond enhancing real-time collaboration, the integration of Autodesk Inventor with Fusion 360 bridged the gap between desktop CAD workflows and cloud-based teamwork. Students used the Desktop Connector to synchronize local Inventor files with the Fusion Team Hub, ensuring seamless transitions between software platforms. This setup enabled iterative design refinement, where models created in Inventor could be further optimized in Fusion 360, mimicking industry-standard engineering workflows [28]. Real-time synchronization eliminated version conflicts, allowing team members to stay aligned on project developments while reinforcing collaborative problem-solving and version control practices.

The integration of Autodesk tools within the CSCL framework resulted in significant educational benefits [29]. Students developed hands-on proficiency with industry-standard software, strengthening their technical literacy in digital design. The course structure fostered collaborative and communication skills, emphasizing the importance of teamwork in engineering settings. By working through iterative design cycles, students gained experience with real-world engineering practices, particularly in manufacturing, product design, and mechanical engineering technology. The use of Fusion 360's third-party integrations further expanded their skill set, providing exposure to simulation tools, CNC programming, additive manufacturing workflows, and augmented/virtual reality visualization techniques for complex assemblies.

By integrating the flipped classroom model with CSCL methodologies, the course provided a structured, active-learning environment that bridged theoretical knowledge with real-world application. This approach promoted peer-driven problem-solving, increased student engagement, and ensured that instructional strategies were aligned with industry demands. The structured digital workflow, fully supported by cloud-based collaboration tools, allowed students to track progress, refine their designs in real time, and actively participate in an authentic engineering design experience. Given the flexibility and scalability of this model, it offers a replicable framework for other educators seeking to integrate similar collaborative learning strategies in engineering and manufacturing technology courses.

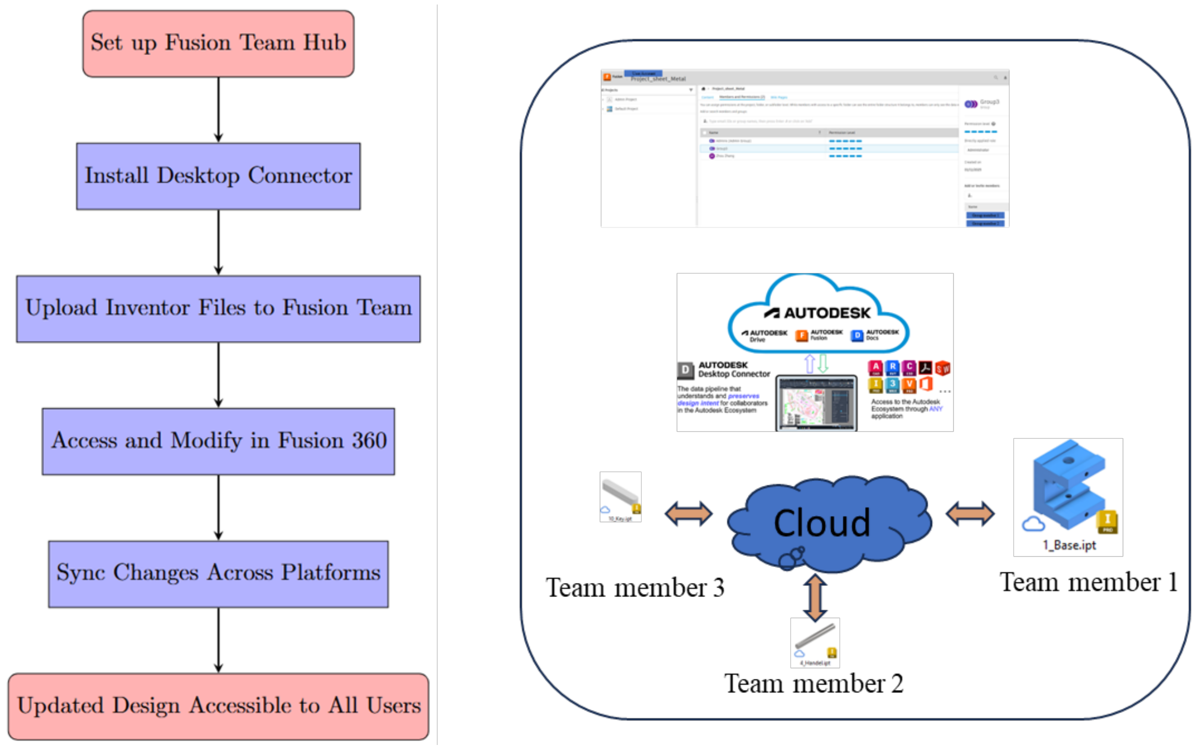


Figure 3: CSCL based collaboration with Inventor, Fusion 360 and Fusion cloud

3.3 Data-Driven Evaluation Framework

Evaluating the flipped classroom implementation required a comprehensive and structured approach to data collection and management. Quantitative and qualitative insights were gathered to assess the impact on student performance, engagement, and learning outcomes. Pre- and post-surveys measured changes in attitudes, perceptions, and satisfaction, offering valuable context for the flipped classroom approach's effectiveness (refer to Table 1). Performance data, including quiz scores, homework results, project outcomes, and exam grades, were analyzed to track academic improvement over the semester.

Student engagement was monitored through attendance and participation logs, capturing dynamics during in-class collaboration. Peer review feedback offered insights into team dynamics and individual contributions, while learning analytics from cloud-based CAD tools tracked progress and engagement with course materials. Pre- and post-test assessments compared knowledge levels, providing clear indicators of learning gains.

Project quality was assessed using industry-relevant criteria, focusing on creativity, functionality, and practical application. Focus groups and interviews gathered qualitative feedback, deepening the understanding of student experiences and challenges.

The course's hierarchical and scaffolded projects progressed from basic jig designs for drilling holes to advanced designs like tumble jigs and sheet metal fixtures. This alignment reinforced theoretical knowledge through practical application. Homework assignments, predominantly in multiple-choice format, ensured consistent reinforcement of core principles.

By integrating structured data collection with scaffolded projects, the evaluation framework provided a comprehensive view of the flipped classroom's impact, capturing its benefits and addressing areas for improvement.

Table 1: Data collection framework

Data Type	Purpose	Data Source	Method of Analysis
Pre- and Post-Surveys	Measure changes in attitudes, perceptions, and satisfaction	Surveys conducted online or in class	Descriptive statistics and thematic analysis
Performance Data	Evaluate academic improvement across quizzes, homework, projects, and exams	Grades and performance metrics	Comparison of scores and trends
Attendance and Participation Logs	Track engagement during collaborative sessions	Class attendance records and activity logs	Engagement frequency and participation levels
Peer Review Feedback	Assess team dynamics and individual contributions in group projects	Peer evaluation forms	Qualitative and quantitative peer evaluation metrics
Learning Analytics	Monitor progress and interaction with cloud-based tools	Analytics from CAD tools and learning platforms	Behavioral analysis and interaction frequency
Pre- and Post-Test Assessments	Quantify knowledge gains before and after the course	Standardized pre- and post-tests	Knowledge gain comparison through statistical tests
Project Outcome Quality	Evaluate creativity and practical application in final projects	Rubrics for assessing final project quality	Rubric-based scoring and qualitative insights
Focus Groups or Interviews	Gather qualitative feedback on student experiences and challenges	Interviews or focus group discussions	Thematic analysis of qualitative responses

4. Outcomes, Evaluation and Discussion

4.1. Outcomes and measurement criteria

The integration of the flipped classroom and CSCL methodologies was evaluated through a structured data collection process. The collected data, as summarized in Table 1, provided insights into the effectiveness of the pedagogy by leveraging both horizontal and vertical comparison groups.

For the horizontal comparison, data were collected across the following dimensions:

1) Performance Data: Academic improvement was tracked through quiz, homework, and exam scores, recorded as percentages (0% to 100%).

2) Attendance Data: Attendance and participation rates during in-class collaborative sessions were logged, expressed as percentages (0% to 100%).
3) Peer Review Feedback: Scores evaluating team collaboration dynamics, rated from 1 (Poor) to 5 (Excellent).
4) Learning Analytics: Metrics derived from cloud-based CAD tools, including:
    - CAD Usage Hours: Total time spent using CAD tools, ranging from 0 to 40 hours.
    - Collaboration Score: Peer-rated collaboration effectiveness, scored from 1 to 5.
5) Project Outcome Quality: Final project scores assessed against industry-relevant criteria such as creativity, functionality, and practical application. Scores were expressed as percentages (0% to 100%).
6) Focus Group Feedback: Qualitative insights gathered through interviews or focus groups, categorized into a scale where 5 indicates "very positive" and 1 indicates "very negative."

For vertical comparisons, the flipped classroom implementation within the same class was analyzed, contrasting performance before and after the midterm. The datasets included:

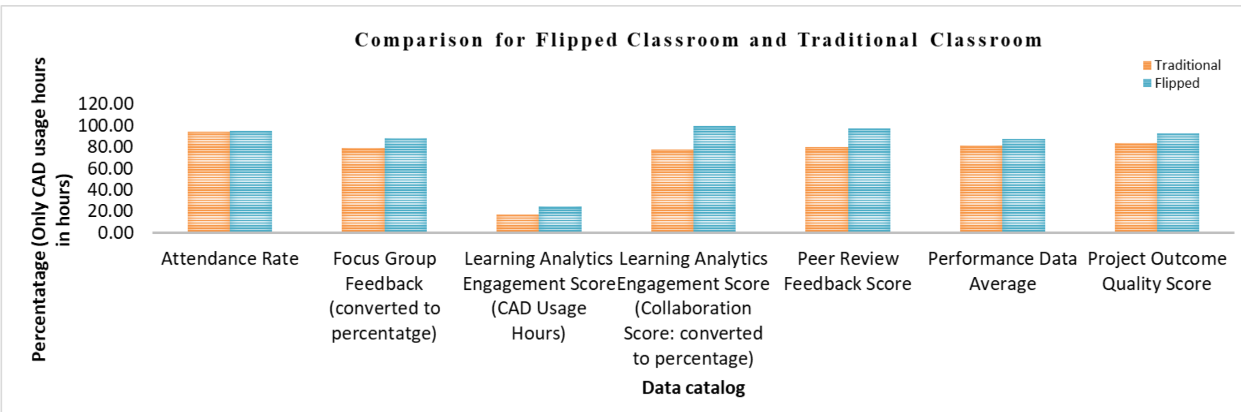
1) Pre- and Post-Survey Scores: Measuring changes in student attitudes and satisfaction, rated on the same 1 to 5 scale.
2) Midterm and Final Exam Scores: Academic performance tracked as percentages (0% to 100%).
3) Project Scores: Comparisons of project quality before and after the midterm.
4) Attendance Data: Participation rates before and after the midterm.

The average values for these datasets were computed, and the results are summarized in Table 2. Figure 4 provides histograms showcasing comparative trends for both horizontal and vertical evaluation groups. These visualizations illustrate the impact of the flipped classroom and CSCL methodologies across various metrics.

Table 2: Data for horizontal and vertical comparison groups

Metric	**Traditional Classroom Mean**		**Flipped Classroom Mean**	
Attendance Rate	93.98		95.08	
Focus Group Feedback	3.95		4.40	
Learning Analytics Engagement Score	CAD Usage Hours	17.3	CAD Usage Hours	24.7
	Collaboration Score	3.89	Collaboration Score	4.97
Peer Review Feedback Score	3.98		4.87	
Performance Data Average	81.50		87.50	
Project Outcome Quality Score	83.30		92.50	

Metrics	Before Midterm	After Midterm
Exam Scores (Midterm vs Final)	80.48	86.29
Project Scores (Before Midterm vs After Midterm)	80.18	96.35
Attendance (Before Midterm vs After Midterm)	84.88	90.17
Pre- and Post-Surveys (converted to percentage)	80.00	96.00



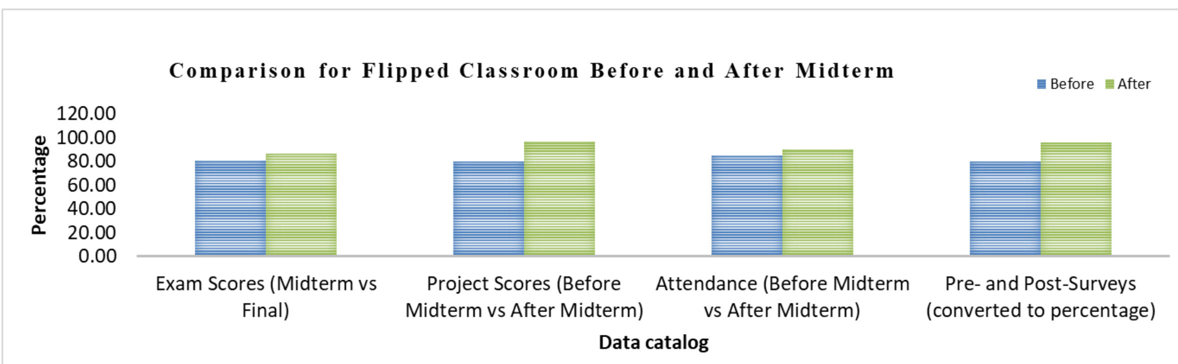


Figure 4: Comparative trends for horizontal and vertical comparison groups

4.2. T-test to evaluate efficiency of flipped classroom and CSCL integration

Given the small sample sizes, selecting the appropriate statistical analysis method was crucial to evaluate the efficiency of the flipped classroom and CSCL integration. While the sample sizes were limited, the datasets exhibited trends of normal distribution, enabling the application of t-tests for analysis.

- Horizontal Comparisons: For comparisons between the flipped and traditional classrooms, an Independent Two-Sample t-Test was applied, as the groups were independent.
- Vertical Comparisons: For within-class comparisons before and after the midterm, a Paired t-Test was used to account for the dependency between observations.

The t-test equations are as follows:

1) For the Independent Two-Sample t-Test:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s_1^2/n_1 + s_2^2/n_2}} \tag{1}$$

Where:

$\bar{x}_1, \bar{x}_2$: sample means of flipped and traditional

s_1^2, s_2^2: sample variances of flipped and traditional

n_1, n_2: sample sizes of flipped and traditional

2) For the Paired t-Test:

$$t = \frac{\bar{d}}{s_d/\sqrt{n}} \tag{2}$$

Where:

$\bar{d}$: mean of the differences between before and after midterm

s_d: standard deviation of the differences

n: Number of observations

These statistical tests were used to determine whether the observed differences in student performance were statistically significant. The results, summarized in Table 3, provide insight into how the flipped classroom approach impacted student learning outcomes compared to traditional instruction. Rounded p-values according to APA guidelines:

- p-values $\geqslant 0.001$ are rounded to three decimal places.
- Extremely small values (e.g., 1.19E-12) are written as $p < 0.001$, following APA standards.
- The hierarchical structure for Learning Analytics Engagement Score has been adjusted for better readability while maintaining statistical accuracy.

Table 3: t-test results

<table>
<tr><th>Metric</th><th colspan="2">t-Statistic</th><th colspan="2">p-Value</th></tr>
<tr><td>Attendance Rate</td><td colspan="2">2.02</td><td colspan="2">0.392</td></tr>
<tr><td>Focus Group Feedback</td><td colspan="2">2.02</td><td colspan="2">0.056</td></tr>
<tr><td rowspan="2">Learning Analytics Engagement Score</td><td>CAD Usage Hours</td><td>2.02</td><td>CAD Usage Hours</td><td>< 0.001</td></tr>
<tr><td>Collaboration Score</td><td>2.02</td><td>Collaboration Score</td><td>< 0.001</td></tr>
<tr><td>Peer Review Feedback Score</td><td colspan="2">2.02</td><td colspan="2">< 0.001</td></tr>
<tr><td>Performance Data Average</td><td colspan="2">2.02</td><td colspan="2">< 0.001</td></tr>
<tr><td>Project Outcome Quality Score</td><td colspan="2">2.02</td><td colspan="2">< 0.001</td></tr>
</table>

Metrics	t-Statistic	p-Value
Exam Scores (Midterm vs Final)	2.09	0.002
Project Scores (Before Midterm vs After Midterm)	2.09	< 0.001
Attendance (Before Midterm vs After Midterm)	2.09	0.076
Pre- and Post-Surveys (converted to percentage)	2.09	< 0.001

4.3. Discussion of Results

The results from Table 2 and Figure 4 strongly indicate that the flipped classroom improved student performance across multiple metrics, including performance data, project outcomes, and peer collaboration. However, the t-test results highlighted two areas with higher p-values: attendance and focus group feedback. While these findings suggest that the flipped classroom's impact on attendance and qualitative feedback appears less pronounced compared to other metrics, it is important to consider alternative explanations. One possibility is that these results stem from sample size limitations rather than an actual lack of effect. A larger sample may provide greater statistical power, potentially revealing more significant trends in these areas. Future research with an expanded cohort, including longitudinal studies across multiple semesters or institutions, could offer a more definitive assessment of how the flipped classroom model influences student engagement and qualitative outcomes. Additionally, refining data collection methods, such as incorporating more detailed attendance tracking and structured qualitative feedback mechanisms, may further clarify the relationship between instructional design and these learning dimensions..

The relatively weaker impact in these areas emphasizes the need for complementary strategies to further enhance engagement and satisfaction. For example, integrating gamification elements or personalized learning pathways could address these gaps. Additionally, focus group insights could be refined through more targeted qualitative analysis to identify underlying issues and potential improvements.

Overall, the integration of the flipped classroom and CSCL demonstrated substantial benefits in enhancing student performance, engagement, and collaboration. These findings underscore the value of innovative teaching methodologies in addressing the limitations of traditional pedagogies and preparing students for real-world challenges in tool design and engineering education.

5. Conclusions

This study explored the integration of flipped classroom and CSCL methodologies in a Tool Design course for Mechanical Engineering Technology students, emphasizing inclusivity and diversity. Through horizontal and vertical comparisons, the research assessed the effectiveness of these approaches in improving academic performance, engagement, collaboration, and practical skills.

The flipped classroom shifted theoretical instruction to pre-class activities like video lectures and CAD tutorials, while in-class sessions focused on collaborative, project-based learning using cloud-based CAD tools. The CSCL model enhanced teamwork both in-class and remotely, replicating real-world engineering environments.

Data from eight metrics, including performance scores, attendance, and project quality, showed significant improvements in most areas, particularly in exam scores, project outcomes, and peer collaboration. However, t-test analyses revealed areas like attendance and qualitative feedback where the impact was less pronounced.

Overall, the integration of flipped classroom and CSCL methodologies proved effective in fostering an inclusive, collaborative learning environment, equipping students with industry-relevant skills for success in tool design and engineering fields.

6. Future Work

Future efforts will address the limitations identified in this study, with a focus on enhancing attendance and qualitative engagement. Several strategies will be implemented to further optimize the flipped classroom and CSCL models:

- Gamification and Incentivization: Introducing gamified elements and reward systems to boost in-class attendance and participation.
- Personalized Learning Pathways: Developing adaptive learning modules tailored to diverse student needs and learning styles, ensuring equitable engagement and comprehension.
- Advanced Learning Analytics: Leveraging AI-driven analytics to gain deeper insights into student behaviors, collaboration dynamics, and performance, enabling real-time support and interventions.
- Scalability and Replication: Expanding the flipped classroom model to larger class sizes and additional courses to evaluate its scalability and general applicability.
- Industry Partnerships: Collaborating with industry professionals to incorporate authentic, real-world design challenges into the curriculum, increasing the relevance and applicability of projects.
- Longitudinal Studies: Conducting longitudinal assessments to evaluate the long-term impact of flipped classrooms on academic and professional success.

Through these initiatives, we aim to refine and expand the application of flipped classroom and CSCL methodologies in engineering education. These efforts will contribute to the development of more effective, inclusive, and industry-aligned pedagogical practices, ultimately enhancing the learning experience and preparing students for real-world engineering challenges.

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