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Boosting Engineering Students' Trigonometry and Solid Mensuration Skills Through Flipped Learning

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Abstract

This study examined the effectiveness of the flipped classroom (FC) approach in enhancing the learning of Plane and Spherical Trigonometry with Solid Mensuration among first-year civil engineering students at the University of Antique. This study employs a quasi-experimental posttest-only control group design. The study compared student perceptions and academic performance under traditional and flipped instructional methods. Findings revealed significantly higher posttest scores for students exposed to the flipped classroom model, indicating improved mastery of mathematical concepts. Students also reported very high levels of engagement, clearer understanding of course content, enhanced problem-solving skills, and greater motivation in the flipped environment. Although collaboration yielded mixed perceptions, the overall results suggest that the flipped classroom is a highly effective pedagogical strategy for strengthening conceptual understanding and analytical skills in engineering mathematics. The approach effectively reverses traditional lecture-homework dynamics by enabling pre-class content review and in-class collaborative problem-solving, fostering critical thinking and analytical competence. The study recommends wider implementation of flipped learning to enrich mathematics education in higher education, particularly in challenging engineering subjects, encouraging educators to adopt this model to advance student outcomes, motivation, and readiness for professional practice. These results align with international trends that emphasize active learning, digital literacy, and student responsibility in contemporary Science, Technology, Engineering, and Mathematics education.

Keywords: Engineering Mathematics, Flipped Classroom, Instructional Effectiveness, Problem-solving Skills, Student Engagement.

Introduction

Teaching and learning processes have undergone significant transformations, particularly in the fields of science, technology, engineering, and mathematics, due to the rapid evolution of technology and educational strategies worldwide. The COVID-19 pandemic accelerated the integration of technology in education (1, 2), which has been applied in mathematics courses, providing innovative insights into remote teaching and learning (3). This study, aligned with the United Nations Sustainable Development Goals (UNSDGs), specifically Goal 4, aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Henceforth, the flipped classroom (FC) promotes student interest, engagement, and collaboration, where traditional lecture and homework elements are reversed. Also, it is emphasized that flipped learning as a teaching innovation leveraging technology intends to help facilitate instruction outside traditional classroom hours, where learning approaches have transformed to focus more on innovative activities, learning-to-learn applications, and personalized learning as educational technology has also progressed (4). In addition, this pedagogical model fosters active learning (5), problem-solving and critical thinking (6), and with technology-aided teaching materials (7), leads to digital literacy, essential skills in the modern global economy. Students learn better through watching videos at their own pace; besides, those with varying levels of prior knowledge can better engage with the material (8). The increasing necessity of effective pedagogical strategies, especially in higher education, to improve learning experiences and student engagement in engineering subjects predominantl y, among non-native English speakers (9). Resources that will enhance the students' self-motivated learning must be provided to improve the overall educational experience in engineering programs. Flipping the classroom means reversing

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the traditional lecture-based teaching method by delivering concepts outside the learning environment (10). In a recent study, found strong agreement on the usefulness of classroom response systems (CRS) for enhancing learning achievements, noted higher dropout rates in fundamental subjects compared to technological modules, and concluded that both students and lecturers are ready for digital teaching, emphasizing the positive impact of technology on student engagement and recommending the development of fair and effective remote evaluation procedures (11). In addition, another study demonstrated that the flipped classroom approach significantly improved undergraduate students' academic performance in Mathematics in the Modern World compared to traditional instruction, confirming its effectiveness as an alternative teaching modality (12).

Within the ASEAN region, countries have increasingly adopted innovative educational methodologies to boost competitiveness and address diverse learner needs, advancing regional integration and human capital development. In fact, a comprehensive review was carried out, where 37.14% of the studies came from Southeast Asia from 2017 to 2023 (13). The review focused on the components of the developed learning models, leading to the synthesis of the mobile problem-based learning FC model, which is suitable for implementation in mathematics education. Hence, in various disciplines like mathematics, FC's adoption is seen as a means to enhance student engagement and learning effectiveness. In the Philippine context, reforms in education have emphasized learner-centered strategies to improve outcomes in science, technology, engineering, and mathematics (STEM), responding to existing challenges of student engagement and comprehension. Philippine higher education institutions during the pandemic quickly adopted flexible learning, supporting the "new normal", integrating the use of technology to maintain quality education amid closures (14). However, challenges persist in applying these models consistently, especially in tertiary education institutions. Locally, at the University of Antique, first-year civil engineering students often face difficulties in mastering fundamental mathematical concepts that are critical for their academic progress and future professional practice. The traditional lecture-based delivery has shown limitations in fully engaging these students and developing a deeper understanding.

Despite the global and regional push towards flipped learning, there is limited empirical research examining its effectiveness within the Philippine tertiary education setting, particularly in engineering programs. Subsequently, this gap indicates the need for localized studies to assess FC approaches and tailor them to the specific learning environments and contexts. Numerous studies have found that the FC approach often leads to better student engagement and academic performance compared to traditional lecture methods. However, not all studies comparing traditional and flipped classrooms in higher education have found positive results. Some research reported no statistically significant differences in examination scores between the two formats, indicating that the flipped approach did not lead to improved student performance by the end of the course (15).

Moreover, the flipped classroom (FC) is well-suited for Plane and Spherical Trigonometry with Solid Mensuration because these subjects demand step-by-step conceptual understanding, spatial visualization, and intensive problem-solving. Under constructivist theory, learners actively construct knowledge through guided problem engagement. The FC structure reallocates class time for scaffolding, collaborative reasoning, and conceptual clarification, rather than relying on passive listening. From a cognitive load theory perspective, prerecorded videos allow students to process formulas, derivations, and geometric relationships at their own pace, pause when necessary, and reduce intrinsic cognitive overload, particularly critical in topics involving multi-step trigonometric transformations and solid geometry computations. These theoretical alignments justify the pedagogical suitability of FC for cognitively demanding engineering mathematics.

Hence, this study aims to investigate the impact of FC instruction on learning Mathematics for first-year civil engineering students at the University of Antique. Moreover, findings from this research will provide evidence-based insights to improve teaching practices, enhance student engagement, and contribute to producing skilled engineering professionals ready to meet 21st-century challenges.

Statement of the Problem

This study aimed to examine the effectiveness of the Flipped Classroom (FC) model in enhancing students' understanding and application of Plane and Spherical Trigonometry with Solid Mensuration among first-year civil engineering students. Specifically, it sought to determine students' perceptions of the course in terms of content delivery, engagement, problem-solving skills, and collaboration when taught using (i) the traditional instructional approach and (ii) the flipped classroom approach. Furthermore, the study investigated whether a significant difference exists in students' academic performance between the traditional and flipped classroom methods.

Hypothesis

There is no significant difference between the scores of the traditional and the flipped classroom approach.

Methodology

The study applied quasi-experimental research with a matched-groups Posttest-Only Control Group Design to evaluate the effectiveness of the FC approach in the Plane and Spherical Trigonometry with Solid Mensuration course. The posttest-only control group design is a practical method in educational contexts where administering a pretest may be impractical or could influence participants' responses (16). The research was structured into three distinct stages: preparation, instruction, and evaluation. The preparation stage spanned one week and involved developing instructional materials, including prerecorded video lectures, instruments, and a perception questionnaire. The instruction stage lasted for six weeks and implemented the FC model under the topic Area of Plane Figures, where students independently review video lectures on YouTube and engage in collaborative problem-solving activities during class. The evaluation stage, lasting one week, involves administering the perception questionnaire to assess learning gains and student perceptions of the intervention.

Figure 1 illustrates the structured process of the flipped classroom approach, which consists of three sequential phases: pre-class, in-class, and post-class activities. In the pre-class phase, students independently engage with instructional materials such as video lectures and readings to acquire foundational knowledge before attending class. During the in-class phase, assignments and problem-solving tasks are completed through guided discussions, collaborative activities, and instructor support, allowing students to apply concepts actively and receive immediate feedback. The post-class phase reinforces learning through review and reflection, strengthening conceptual understanding, procedural fluency, and analytical competence in mathematics.

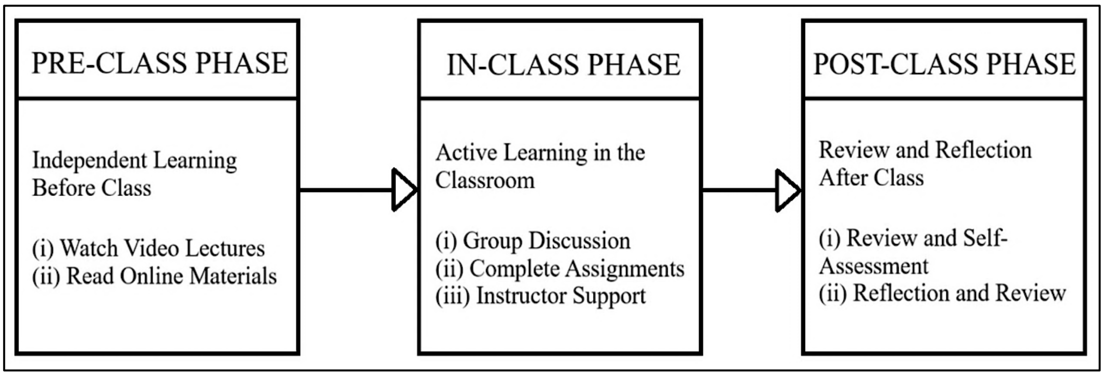

Figure 1: Process Flow of the Flipped Classroom Approach

The respondents for this study were first-year civil engineering students enrolled in the Plane and Spherical Trigonometry with Solid Mensuration course. A Completely Randomized Block Design (CRBD) method was used to select participants who met the inclusion criteria, which included completing all stages of the study, such as instruction, posttest, and questionnaire. Respondents meeting the inclusion criteria are grouped (blocked) based on a certain characteristic, like performance level. Thirty respondents were randomly selected and assigned to different instructional methods. They represented similar performance strata, such as low, middle, and high levels of cognitive ability, making the comparison between the two instructional methods more balanced and fairer.

On the other hand, the study employed two primary research instruments: a posttest and a perception questionnaire. The posttest consists of 15 items covering three key topics on the Area of Plane Figures. The test underwent content validation by subject-matter experts. The perception questionnaire comprises 25 Likert-scale items from "Strongly Agree" to "Strongly Disagree", designed to assess students' views on the FC approach. Pilot testing was conducted with a small group of engineering students outside the main sample to check clarity, reliability, and consistency. The pilot test was conducted in another engineering school outside Antique and yielded a Cronbach's alpha value of 0.84, indicating high internal reliability and consistency of the questionnaire items. Thus, the posttest serves as a direct indicator of students' mastery of the cognitive competencies targeted by the course. On the other hand, the perception questionnaire was designed to measure dimensions that support achievement of these same learning goals, namely, engagement, clarity of content delivery, confidence in problem-solving, and collaboration. These constructs are pedagogically linked to successful mathematical performance, particularly in engineering education, where analytical reasoning and self-regulated learning are essential. Importantly, the instruments complement the course results and learning objectives in a coherent manner.

All statistical analyses, including the Kolmogorov–Smirnov test, Shapiro–Wilk test, and independent samples t-test, were performed using IBM SPSS Statistics version 26.0, with the level of significance set at $\alpha = 0.05$.

For the inclusion criteria, the study included research that focused on the FC approach, documents written in English, publications between 2020 and 2025 publications, and included in the review were the important search terms or key phrases within the titles, abstracts, and the specific keywords of documents. On the other hand, the study will exclude documents published in non-English languages, documents that are not related to the flipped classroom, and documents outside the STEM field.

The researcher recognized that each person is entitled to their right to make their own decisions and thus, certain ethical issues were taken into consideration in the conduct of the study. Basic human rights and utmost respect were observed throughout the research process. Probable risks and discomforts, and any anticipated benefits, were identified. The ethical guidelines for the conduct of research were the following: right to consent, information, and full disclosure, right to self-determination, right to confidentiality, privacy, and anonymity, and right to protection from harm.

Results

Students' Perceptions through Traditional the Approach

The results present the descriptive statistics of students' perceptions under the traditional instructional approach across five key dimensions: content, delivery, engagement, problem-solving skills, and collaboration. The mean scores and standard deviations provide a comprehensive overview of how students evaluated the effectiveness of the conventional teaching method.

Table 1: Result of Students' Perceptions through the Traditional Approach

Category	Indicators	Mean (M)	SD	Description
Content	(i) I find the course content relevant to my academic goals.	3.87	0.743	H
	(ii) I understand the key concepts presented in the course materials.	3.87	0.640	H
	(iii) The learning materials are clear and comprehensive.	4.13	0.640	H
	(iv) The content encourages me to think critically about mathematical problems.	4.33	0.488	VH
	(v) I feel confident applying the concepts learned to solve related problems.	4.13	0.640	H
Delivery	(i) The method of content delivery suits my learning style.	4.47	0.516	VH
	(ii) The pace of instruction is appropriate for my understanding.	4.07	0.704	H
	(iii) The explanations provided during lessons clarify difficult concepts.	2.67	0.724	M
	(iv) The mix of instructional activities helps me learn the material better.	2.73	0.884	M
	(v) I receive helpful feedback from my instructor during lessons.	2.00	0.845	L

Engagement	(i) I actively participate during class activities.	3.33	0.816	M
	(ii) The learning approach keeps me motivated to study Mathematics.	3.67	0.976	H
	(iii) I spend adequate time preparing for each class.	2.07	1.223	L
	(iv) I feel interested in the subject matter covered in this course.	4.07	0.594	H
	(v) I take responsibility for my own learning in this course.	2.20	1.014	L
Problem-solving Skills	(i) My problem-solving skills have improved through this course.	2.20	0.862	L
	(ii) The course provides enough opportunities to practice solving problems.	3.87	0.743	H
	(iii) I am confident in my ability to approach complex mathematical problems.	3.87	7.571	H
	(iv) The course helps me develop analytical thinking skills relevant to engineering.	4.80	1.246	VH
	(v) I feel well-prepared for exams because of the problem-solving practice.	2.47	1.298	L
Collaboration	(i) Working with classmates helps me understand the material better.	2.07	1.033	L
	(ii) Group activities encourage effective communication among students.	2.60	1.298	L
	(iii) I learn from the ideas shared by peers during collaborative activities.	2.53	1.407	L
	(iv) I feel comfortable sharing my thoughts and solutions in class.	2.73	1.668	M
	(v) Collaborating with classmates improves my overall learning experience.	2.47	1.246	L

Note: (4.21-5.00) - Very high (VH); (3.41-4.20) - High (H); (2.61-3.40) - Moderate (M); (1.81-2.60) - Low (L); (1.00-1.80) - Very Low (VL)

Table 1 presents students' perceptions of the traditional instructional approach across five dimensions: content, delivery, engagement, problem-solving skills, and collaboration. In terms of content, the highest mean was recorded for "The content encourages me to think critically about mathematical problems" [M = 4.33, SD = 0.488], followed by "The learning materials are clear and comprehensive" [M = 4.13] and "I feel confident applying the concepts learned" [M = 4.13]. The lowest content ratings were observed in "I find the course content relevant to my academic goals" and "I understand the key concepts presented" [M = 3.87]. Although still high, these comparatively lower means suggest that while students recognize the course's analytical rigor, alignment with personal academic goals, and conceptual clarity may not be maximized. In the delivery category, the highest mean was "The method of content delivery suits my learning style" [M = 4.47, SD = 0.516], indicating strong compatibility between lecture style and student preference. However, the lowest mean in the entire table appeared in delivery: "I receive helpful feedback from my instructor during lessons" [M = 2.00]. Other relatively low indicators included "The explanations provided during lessons clarify difficult concepts" [M = 2.67] and "The mix of instructional activities helps me learn better" [M = 2.73]. This disparity suggests that although students are comfortable with lecture-based delivery, it may lack sufficient formative feedback and instructional variation necessary for deeper conceptual processing. Regarding engagement, the highest-rated item was "I feel interested in the subject matter covered in this course" [M = 4.07, SD = 0.594], followed by motivation to study mathematics [M = 3.67]. Conversely, the lowest engagement ratings were "I spend adequate time preparing for each class" [M = 2.07] and "I take responsibility for my own learning in this course" [M = 2.20]. These results indicate a passive learning tendency, where interest exists but self-regulated preparation and ownership of learning remain weak under the traditional model. Furthermore, for problem-solving skills, the highest mean across all categories was recorded for "The course helps me develop analytical thinking skills relevant to engineering" [M = 4.80, SD = 1.246], demonstrating that the traditional approach effectively fosters higher-order analytical reasoning. However, the lowest values within this category were "My problem-solving skills have improved through this course" [M = 2.20] and "I feel well-prepared for exams because of the problem-solving practice" [M = 2.47]. This contrast suggests that while students recognize the course's theoretical contribution to analytical thinking, they do not perceive substantial procedural skill enhancement or examination readiness. Finally, collaboration yielded consistently low results. The lowest mean was “Working with classmates helps me understand the material better” [M = 2.07], followed by “Collaborating with classmates improves my overall learning experience” [M = 2.47] and “I learn from the ideas shared by peers during the collaborative activities” [M = 2.53]. Even the highest collaboration score, “I feel comfortable sharing my thoughts and solutions in class” [M = 2.73, SD = 1.668], remained only moderate. These findings indicate that the traditional instructional format minimally promotes peer interaction and collaborative knowledge construction.

Moreover, the analysis of students' perceptions using the traditional instructional approach reveals notable patterns, as shown in Table 1. The results imply that while the traditional instructional approach remains effective in cultivating critical and analytical thinking, it does not sufficiently translate conceptual exposure into active skill development, self-regulated learning, or collaborative competence. Students clearly recognize the intellectual rigor of the course and its contribution to analytical reasoning in engineering contexts; however, the limited perceptions of improvement in procedural problem-solving and examination readiness suggest a disconnect between theoretical understanding and applied mastery. This indicates that lecture-dominated instruction may support cognitive recognition of concepts but may not adequately reinforce iterative practice, feedback-driven correction, and strategic problem-solving refinement. Furthermore, the consistently low ratings in engagement, responsibility, and collaboration highlight a structural limitation of the traditional model. The absence of strong formative feedback mechanisms, limited instructional variation, and minimal structured peer interaction appear to constrain deeper learning internalization. In engineering education, where teamwork, communication, and applied analytical competence are essential professional skills, such limitations may hinder the development of holistic readiness. Collectively, these findings strongly suggest the need for instructional reform that integrates interactive learning strategies, structured collaborative activities, and continuous feedback systems to bridge the gap between conceptual understanding and applied problem-solving proficiency.

The graph below shows that under the traditional instructional approach revealed in Figure 2, Content received the highest mean [M = 4.07], indicating that students perceive the material as clear, relevant, and intellectually stimulating. Problem-Solving [M = 3.44] also scored relatively high, suggesting that students recognize its value in developing analytical and engineering reasoning skills. However, Delivery [M = 3.19] and Engagement [M = 3.07] were only moderate, implying limited stimulation of active participation, while Collaboration [M = 2.48] had the lowest mean, highlighting minimal opportunit ies for peer interaction and cooperative learning in the traditional approach.

The findings imply that while the traditional instructional approach is effective in presenting structured content and fostering analytical reasoning, it does not sufficiently promote active engagement or collaborative learning. The strong perception of content clarity and intellectual rigor suggests that foundational knowledge acquisition is well supported; however, the moderate ratings in delivery and engagement indicate that students may remain passive recipients of information rather than active constructors of knowledge. Furthermore, the notably low collaboration rating highlights a critical limitation in preparing students for engineering practice, where teamwork, communication, and cooperative problem-solving are essential competencies.

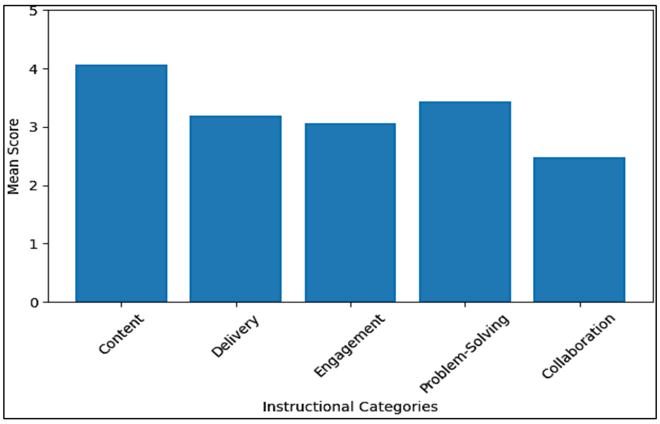

Figure 2: Category Mean Scores under the Traditional Approach

The contrast among the category mean scores underscores a clear instructional imbalance in cognitive development through content exposure, which is strong, yet interactive and student-centered elements remain comparatively weak. In engineering mathematics, where applied reasoning and collaborative problem-solving are fundamental, this imbalance may constrain the development of comprehensive professional skills. Collectively, these results demonstrate that although the traditional approach performs well in structured content delivery, it requires enhancement in engagement strategies, formative feedback mechanisms, and collaborative learning structures to optimize overall educational effectiveness and produce well-rounded engineering graduates.

Students' Perceptions through Flipped Classroom Approach

The results present the descriptive statistics of students' perceptions under the flipped classroom approach across five instructional dimensions: content, delivery, engagement, problem-solving skills, and collaboration. The mean scores and standard deviations provide an overall evaluation of how students perceived the effectiveness of the flipped instructional model.

Table 2: Result of Students' Perceptions through Flipped Classroom Approach

Category	Indicators	Mean (M)	SD	Description
Content	(i) I find the course content relevant to my academic goals.	4.27	0.704	VH
	(ii) I understand the key concepts presented in the course materials.	4.33	0.724	VH
	(iii) The learning materials are clear and comprehensive.	4.67	0.488	VH
	(iv) The content encourages me to think critically about mathematical problems.	4.60	0.507	VH
	(v) I feel confident applying the concepts learned to solve related problems.	4.67	0.488	VH
Delivery	(i) The method of content delivery suits my learning style.	4.73	0.458	VH
	(ii) The pace of instruction is appropriate for my understanding.	4.80	0.414	VH
	(iii) The explanations provided during lessons clarify difficult concepts.	4.80	0.414	VH
	(iv) The mix of instructional activities helps me learn the material better.	4.60	0.507	VH
	(v) I receive helpful feedback from my instructor during lessons.	4.73	0.458	VH
Engagement	(i) I actively participate during class activities.	4.67	0.488	VH
	(ii) The learning approach keeps me motivated to study Mathematics.	4.80	0.414	VH
	(iii) I spend adequate time preparing for each class.	4.80	0.414	VH
	(iv) I feel interested in the subject matter covered in this course.	4.47	0.516	VH
	(v) I take responsibility for my own learning in this course.	4.53	0.516	VH
Problem-Solving Skills	(i) My problem-solving skills have improved through this course.	4.73	0.458	VH
	(ii) The course provides enough opportunities to practice solving problems.	4.73	0.458	VH

	(iii) I am confident in my ability to approach complex mathematical problems.	4.00	0.756	H
	(iv) The course helps me develop analytical thinking skills relevant to engineering.	4.67	0.488	VH
	(v) I feel well-prepared for exams because of the problem-solving practice.	4.67	0.488	VH
Collaboration	(i) Working with classmates helps me understand the material better.	2.93	0.799	M
	(ii) Group activities encourage effective communication among students.	4.67	0.488	VH
	(iii) I learn from the ideas shared by peers during collaborative activities.	4.60	0.507	VH
	(iv) I feel comfortable sharing my thoughts and solutions in class.	3.27	1.100	M
	(v) Collaborating with classmates improves my overall learning experience.	4.47	0.743	VH

Note: (4.21-5.00) - Very high (VH); (3.41-4.20) - High (H); (2.61-3.40) - Moderate (M); (1.81-2.60) - Low (L); (1.00-1.80) - Very Low (VL)

The analysis of students' perceptions under the flipped classroom approach revealed consistently high evaluations across all instructional dimensio ns, as revealed in Table 2. In terms of content, the highest ratings were observed in "The learning materials are clear and comprehensive" [M = 4.67, SD = 0.488] and "I feel confident applying the concepts learned to solve related problems" [M = 4.67, SD = 0.488], indicating very high agreement. Other content indicators, such as understanding key concepts [M = 4.33] and relevance to academic goals [M = 4.27], also remained very high, demons trating strong conceptual clarity and applicability. For delivery, the highest means were recorded in "The pace of instruction is appropriate for my understanding" [M = 4.80, SD = 0.414] and "The explanations provided during lessons clarify difficult concepts" [M = 4.80, SD = 0.414]. These findings highlight the effectiveness of the flipped structure in facilitating comprehension of complex mathematical procedures. Other delivery indicators, including receiving helpful feedback [M = 4.73] and suitability to learning style [M = 4.73], also showed very high ratings, while the mix of instructional activities, though slightly lower [M = 4.60], still reflected strong instructional effectiveness. Moreover, in the engagement dimension, the highest ratings were found in "The learning approach keeps me motivated to study Mathematics" [M = 4.80, SD = 0.414] and "I spend adequate time preparing for each class" [M = 4.80, SD = 0.414], indicating strong promotion of motivation and self-regulated learning. Other engagement indicators, such as active participation [M = 4.67] and responsibility for learning [M = 4.53], further confirm high levels of student involvement. Regarding problem-solving skills, the highest means were observed in "My problem-solving skills have improved through this course" [M = 4.73, SD = 0.458] and "The course provides enough opportunities to practice solving problems" [M = 4.73, SD = 0.458], suggesting substantial enhancement in procedural fluency and analytical competence. Additional indicators, including development of analytical thinking skills [M = 4.67] and exam preparedness [M = 4.67], remained very high, while confidence in approaching complex mathematical problems, though slightly lower [M = 4.00], still fell within the high descriptive range. In contrast, collaboration demonstrated comparatively greater variation. The highest rating was recorded for "Group activities encourage effective communication among students" [M = 4.67, SD = 0.488], followed by learning from peers' ideas [M = 4.60] and improved overall learning experience through collaboration [M = 4.47]. However, the lowest values in the entire table were found in "Working with classmates helps me understand the material better" [M = 2.93] and "I feel comfortable sharing my thoughts and solutions in class" [M = 3.27], indicating moderate levels of comfort in peer-assisted learning.

The results in Table 2 strongly suggest that the flipped classroom approach fosters a highly supportive and cognitively enriching learning environment in engineering mathematics. The consistently elevated perceptions across content clarity, instructional delivery, engagement, and problem-solving development indicate that the flipped structure successfully integrates conceptual understanding with active application. The strong ratings in motivation, preparation, and skill improvement imply that students are not merely exposed to mathematical concepts but are actively internalizing and applying them. This reflects a meaningful shift from passive reception of information toward self-regulated, responsibility-driven learning, which is essential for mastering complex trigonometric and solid mensuration principles.

Furthermore, the high evaluations in delivery and feedback demonstrate that the flipped model enhances instructional responsiveness and reduces cognitive overload by allowing students to process foundational content prior to class and use contact time for clarification and guided practice. Such an approach strengthens analytical competence and procedural fluency, aligning closely with the demands of engineering education. Although collaboration showed some variability in comfort levels, the overall positive perceptions of communication and peer learning indicate that structured in-class activities promote interactive engagement more effectively than traditional lecture-based formats. Collectively, these findings provide strong pedagogical justification for broader adoption of the flipped classroom model, as it not only enhances conceptual mastery and problem-solving capability but also cultivates learner autonomy, motivation, and professional readiness in mathematics-intensive disciplines.

The graph below illustrating the category mean scores under the flipped classroom approach visually reinforces the strong positive perceptions revealed in Figure 3. Among the five instructional dimensions, Delivery obtained the highest overall mean [M = 4.73], followed closely by Engagement [M = 4.65], Problem-Solving [M = 4.56], and Content [M = 4.51]. These results indicate that students particularly valued the pacing of instruction, clarity of explanations, and the structured learning process embedded in the flipped model. The elevated engagement further suggests that the approach effectively promotes preparation, motivation, and active classroom participation, critical components in mastering complex engineering mathematics. Although Collaboration recorded the lowest category mean [M = 3.99], it still falls within the high descriptive range. The comparatively lower bar height in this category reflects variability in students' comfort with peer interaction rather than a fundamental weakness of the approach. The visual contrast between the consistently high bars for content, delivery, engagement, and problem-solving and the relatively lower collaboration bar highlights an important instructional insight: while the flipped classroom significantly strengthens cognitive processing, motivation, and procedural competence, additional scaffolding strategies may be needed to fully optimize collaborative learning dynamics.

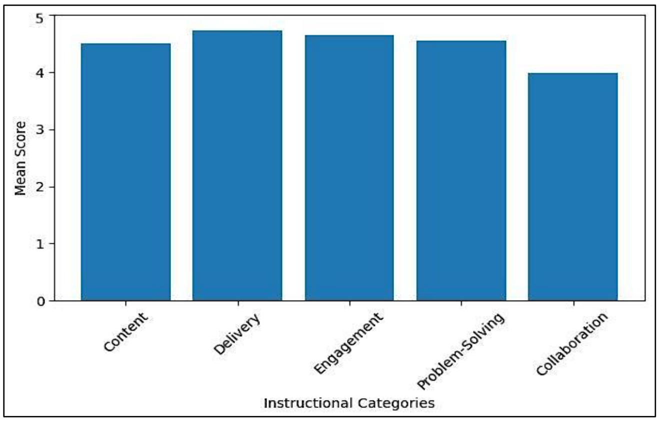

Figure 3: Category Mean Scores under the Flipped Classroom Approach

Furthermore, the findings indicate that the flipped classroom approach creates a highly supportive and learner-centered instructional environment that strengthens both conceptual understanding and applied competence in engineering mathematics. The strong ratings in delivery, engagement, and problem-solving suggest that the structured combination of pre-class preparation and in-class active learning enhances clarity of instruction, promotes sustained motivation, and facilitates deeper cognitive processing. This implies that the flipped model effectively shifts students from passive knowledge reception to active knowledge construction, thereby fostering greater ownership of learning and improved procedural mastery.

Comparison of Scores between Traditional and Flipped Classroom Approaches

The independent samples t-test comparing the Flipped Classroom and Traditional Approach groups revealed a mean difference of 6.133 [SD = 7.736] with t [14] = 3.071 and p = .008, which is below the α = 0.05. This indicates that students exposed to the flipped classroom performed significantly better in the posttest than those under the traditional method. The higher mean score of the flipped group suggests that this instructional model more effectively enhances students' conceptual understanding and mastery of Plane and Spherical Trigonometry with Solid Mensuration, whereas the traditional approach, although foundational, appears less effective in promoting higher achievement. Beyond statistical significance, the magnitude of the difference was assessed using Cohen's *d*, calculated from the mean difference and standard deviation, yielding an effect size of approximately 0.79, which represents a large effect. The 95% confidence interval for the mean difference excluded zero, confirming the stability and consistency of the positive instructional impact. Practically, a gain of more than six points on a 15-item posttest reflects a meaningful improvement in conceptual mastery and procedural accuracy, demonstrating that the flipped classroom approach produces both statistically and educationally significant learning gains.

As presented in Table 3, the independent samples t-test results indicate a statistically significant difference between the posttest scores of students in the flipped classroom and traditional instructional groups.

Table 3: Independent Samples t - Test Result Comparing the Posttest Scores Between the Flipped Classroom and Traditional Approach Groups

Pair	Mean	Std. Deviation	t	Df	Sig.
Flipped Classroom Posttest - Traditional Posttest	6.133	7.736	3.071	14	.008

The findings signify that the Flipped Classroom methodology promotes improved academic performance in mathematics, which can be attributed to its instructional design, where students engage with learning materials beforehand and utilize classroom time for active problem-solving, collaboration, and conceptual reinforcement. This outcome carries substantial instructional implications. The superior performance of students under the flipped model suggests that restructuring classroom time to prioritize active problem-solving, guided practice, and conceptual clarification produces measurable academic gains. The results imply that learning in engineering mathematics becomes more effective when students engage with foundational content before class and use face-to-face sessions for higher-order cognitive processing. These findings further suggest that the flipped classroom enhances not only content comprehension but also procedural mastery and analytical reasoning. The improved performance indicates that students are better able to internalize mathematical principles and apply them accurately in structured assessments. This reinforces the pedagogical value of active learning environments, where immediate feedback, collaborative exercises, and instructor facilitation support deeper conceptual consolidation. In contrast, traditional lecture-based approaches may provide conceptual exposure but may not sufficiently support applied skill development at the same level. From a curriculum development perspective, the results provide empirical justification for integrating flipped instructional strategies into engineering mathematics programs. The significant performance gap highlights the potential of the flipped model to improve student achievement in cognitively demanding subjects such as plane and spherical trigonometry with solid mensuration. This suggests that institutions seeking to enhance mathematics performance and reduce academic difficulty in foundational engineering courses should consider adopting structured flipped methodologies.

Moreover, the findings imply broader professional implications. Engineering education requires graduates who possess strong analytical reasoning, independent problem-solving abilities, and the capacity to apply theoretical knowledge to real-world contexts. The improved outcomes associated with the flipped classroom suggest that this model better prepares students for these professional demands by fostering active engagement, sustained practice, and deeper learning retention.

Discussion

The results suggest that while the traditional approach can develop critical analytical skills and maintain student interest to some degree, it struggles significantly with fostering collaboration, active engagement, and practical problem-solving application. The low collaboration scores indicate a critical weakness in social and peer-supported learning environments, which are vital for engineering education. This gap points to potential benefits of employing pedagogical strategies that enhance interactive and personalized learning experiences. Consequently, strong collaborative intention leads to greater participation in group work, higher course retention, increased generation of new ideas, and an improved learning experience (17). Improving explanations and providing more varied, engaging instructional activities could remedy some of the challenges seen with the traditional approach. These findings imply that reforms aimed at integrating more active learning, such as flipped classrooms or collaborative problem-solving sessions, could substantially elevate student engagement, preparation, and collaboration skills. It may foster deeper conceptual understanding, enhance metacognitive awareness, strengthen problem-solving skills, and promote learner autonomy by connecting mathematical concepts to real-world contexts (18).

To deepen the interpretation of the quantitative findings, classroom observations and informal student reflections were examined during the implementation of the flipped classroom (FC) approach. Observational notes indicated that students engaged more actively in group activities, peer explanation, and instructor consultation during in-class problem-solving sessions. Several students expressed that watching prerecorded lectures allowed them to pause and replay difficult solutions, which reduced anxiety when solving Area of Plane Figures problems. Moreover, learners reported feeling more prepared before coming to class, enabling them to participate confidently in analytical discussions. These insights support the quantitative results, particularly the very high ratings in engagement, delivery clarity, and problem-solving improvement. The triangulation of classroom behavior, student reflections, and posttest performance strengthens the conclusion that the FC approach enhances conceptual knowledge and procedural fluency in engineering mathematics.

The effectiveness of the FC methodology in transforming mathematics education, particularly in demanding engineering-related mathematical courses. The very high scores in content clarity, critical thinking, and problem-solving readiness imply that flipped classrooms can better cater to diverse learning paces and styles and promote deeper mastery of complex mathematical concepts. This supports active learning principles, where students take responsibility for pre-class preparation, enabling more interactive, collaborative, and problem-based learning during class time. Also, enhanced engagement and motivation are critical in mathematics education, where student anxiety and disengagement are common barriers. The FC reduces these by fostering greater student ownership of learning and providing more meaningful interaction with peers and instructors during activities. However, the moderate collaboration findings highlight a need to scaffold collaborative learning more effectively through structured group roles, peer feedback training, or confidence-building strategies, to fully leverage peer learning benefits.

The implications of these findings are comprehensive for mathematics teaching and learning. Implementation of the FC approach can foster deeper conceptual understanding, critical thinking, and problem-solving skills as students actively interact with mathematical content rather than passively receiving information. The FC approach in mathematics, particularly in geometry, significantly improves students' performance and interest by allowing them to learn concepts at home and engage in interactive activities in class, with research showing no gender difference in outcomes and recommending further study of demographic factors and innovative learning resources to sustain engagement and achievement (19). Educators are encouraged to implement the FC model influenced by the most current trends of research, improving student engagement, fostering motivation, learner autonomy, self-regulation, and meeting the learning outcomes (20). With this, it encourages greater student interest, responsibility for learning, and peer collaboration, which are essential for mastering complex mathematical principles. Moreover, by reversing the traditional lecture-homework format, the FC allows mathematics educators to utilize class time for differentiated instruction, immediate feedback, and interactive activities that build higher-order thinking skills fundamental to mathematics education. This pedagogical shift supports the development of self-regulated learners better prepared to tackle mathematical challenges in academic and real-world contexts.

However, the implementation of appropriate mathematics teaching approaches by teachers can significantly enhance learners' motivation and willingness to learn (21); consequently, mathematics researchers have continuously explored innovative strategies to improve students' achievement and interest in mathematical concepts (22). In particular, learners who were taught mathematics through a flipped classroom approach obtained higher mathematics scores and demonstrated greater interest compared with those instructed using conventional methods (19). The present findings align with prior research demonstrating that flipped learning enhances academic performance and engagement in mathematics and engineering education. Similar to previous studies (23), students in the flipped condition exhibited significantly higher achievement scores compared to those in traditional settings. Consistent gains in mathematical reasoning and active participation under flipped instruction have also been documented (20). However, unlike some studies that reported no significant difference in long-term retention or project output quality (12, 15), the current study found a large effect size [$d \approx 0.79$], indicating substantial improvement in short-term conceptual mastery. This divergence may be attributed to the structured in-class scaffolding and guided problem-solving sessions specifically tailored to trigonometry and solid mensuration, which are highly procedural and benefit from iterative practice. The flipped classroom has been widely recommended as an effective instructional strategy for teaching mathematics (24, 25). Thus, while global literature supports flipped learning as an active methodology, this study contributes localized empirical evidence within Philippine engineering education, highlighting its strong impact on analytical mathematics performance in cognitively demanding subjects.

Collectively, the t-test results confirm the effectiveness of the FC approach in improving first-year civil engineering students' mathematics performance in Plane and Spherical Trigonometry with Solid Mensuration. Mathematics educators should consider adopting this instructional model to enhance student learning outcomes, cultivate analytical and problem-solving competencies, and ultimately contribute to sustainable improvements in mathematics education.

This study is limited by its posttest-only design, relatively small sample size, and single-institution setting, which may restrict the generalizability of the findings. The six-week duration of implementation also limits conclusions regarding long-term retention and sustained academic impact. Future research should employ longitudinal and multi-institutional designs, incorporate larger samples, and examine the effectiveness of the flipped classroom across other engineering mathematics courses to strengthen external validity and scalability.

Conclusion

The FC approach is an effective instructional strategy for enhancing mathematics learning among first-year civil engineering students. Empirical evidence from the study indicates that students exposed to the FC model achieved significantly higher posttest scores compared to those taught via traditional lecture methods. The methodological design, which emphasizes pre-class engagement with lecture materials and active, collaborative problem-solving during class, fosters deeper conceptual understanding, critical thinking, and improved problem-solving skills.

The flipped classroom also promotes increased student engagement, motivation, and responsibility for learning, which are crucial for mastering challenging mathematical concepts such as plane and spherical trigonometry with solid mensuration. These pedagogical benefits align with global trends in mathematics education that highlight active learning, digital literacy, and student-centered approaches as key drivers of academic success.

Furthermore, this approach enables educators to use classroom time more efficiently, focusing on differentiated instruction and immediate feedback, thereby addressing diverse learning needs and enhancing overall mathematics performance. Given the positive outcomes in both academic achievement and student perception, the FC model should be considered a valuable alternative or complement to traditional teaching in higher education mathematics courses, particularly in engineering disciplines.

Based on the findings, higher education institutions, particularly engineering programs, are strongly encouraged to adopt the flipped classroom model in mathematics courses to enhance conceptual mastery, analytical reasoning, and problem-solving performance. Instructors should incorporate structured collaborative strategies, formative pre-class assessments, and visualization tools to maximize engagement and deepen understanding of trigonometry and solid mensuration concepts. Future research should examine long-term retention and scalability across other engineering subjects to further validate and strengthen the instructional impact of the flipped approach.

Abbreviations

ASEAN: Association of Southeast Asian Nations, CRBD: Completely Randomized Block Design, CRS: Classroom Response Systems, FC: Flipped Classroom, LCA: Life Cycle Engineering, SPSS: Statistical Package for the Social Sciences, STEM: Science, Technology, Engineering, and Mathematics, UNSDG: United Nations Sustainable Development Goals.

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Author Contributions

John Rogel S Ursua: conceptualization, methodology, data collection, analysis, writing of the original draft, Jahfet N Nabayra: validation, review, editing, supervision.

Conflict of Interest

The authors declare no conflict of interest related to the study.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon request.

Declaration of Artificial Intelligence (AI) Assistance

Generative AI and AI-assisted technologies were used in the writing process as follows: Perplexity AI enhanced the substance and clarity of the manuscript by refining phrasing and structure in sections, while Grammarly performed grammar checking and style corrections. Authors reviewed and approved all changes to ensure accuracy and originality.

Ethics Approval

This study obtained ethics approval from the University of Antique Research Ethics Review Committee. Written informed consent was secured from all participants before the commencement of data collection.

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