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Utilizing Flipped Classroom and the First Principles of Effective Instruction in Teaching Finite Geometry

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The flipped classroom approach has been used as a variation of digital learning even before the covid-19 pandemic. Using this approach and the First Principles of Effective Instruction, this study determined and compared the proving skills of higher education students in finite geometries using true experimental research involving two equivalent classes in Modern Geometry. Data on proving competencies were gathered from the 27 pairs of randomly selected respondents and were subjected to data exploratory analysis to ensure the appropriateness of statistical tools for data analysis. Results reveal that both classes performed equivalently in the pretest. However, the flipped class exhibited a statistically significant improvement in the posttest and in-class activities than the non-flipped class. Additionally, the flipped class was found to have equivalent performances in both individual and group in-class activities. The results showed that necessary competencies in proving theorems can be attained using the flipped classroom approach following the activation, demonstration, application, and integration phases of instruction. The study recommended using the approach to support students learning achievement, performance enhancement, and active learning environment. It can also be incorporated into crafting an adaptive learning continuity plan for the post-pandemic recovery period and beyond.

Keywords: active learning, critical thinking and problem-solving skills, finite geometry, first principles of effective instruction, flipped classroom, pandemic, proving theorems

INTRODUCTION

The primary goal of mathematics education is to develop students' problem-solving and critical-thinking skills (Puchongprawet & Chantraukrit,2022; Magaji, 2021; Al-Zoubi & Suleiman, 2021). Most education experts agree that educators must design activities that actively engage students in what they are learning to achieve learning outcomes (Choi et al., 2021; Xu et al., 2020). Özbay and Çınar (2021) urged teachers to employ instructional pedagogies that help students to learn and apply critical thinking and

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problem-solving. Among the student-centered instructional pedagogies, the flipped classroom approach stands out primarily because it is flexible and adaptable (Zainuddin, 2018) and technology-driven (Alzoebi et al., 2023; Priporas et al., 2017).

Over the past years, the flipped classroom approach has gained popularity as a pedagogical approach in many subject disciplines across education levels around the world (Khasanah & Anggoro, 2022; Zhu et al., 2020; Strelan et al., 2020; van Alten et al., 2020; Jwaifell et al., 2018; Chen et al., 2017). It was noted as an essential breakthrough in educational technology and has become a strongly advocated approach to student learning in both K to 12 and higher education across various fields and disciplines (Lashari et al., 2022; Hew et al., 2021; Lencastre et al., 2020).

The flipped classroom approach is a pedagogical model that reverses the typical lecture and assignment elements of a course or subject discipline (Unal & Unal, 2017). In this approach, concepts are introduced before the class schedule, and the actual class time is devoted to guiding students through active, practical, innovative applications of the concepts (Shana & Alwaely, 2021; Zhu et al., 2020).

In essence, the flipped classroom approach consists of pre-class activities such as viewing video tutorials before the actual class schedule and completing individual or group tasks during the in-class phase, where face-to-face interaction between the teachers and students is vital and necessary (Wells-Beede, 2020). Considering this, the in-class time is characterized as student-centered, where interactive activities such as collaborative problem-solving can be implemented with the guidance of the teacher or instructor (Ward et al., 2018; Cho & Lee, 2018; Van Sickle, 2016; Sohrabi & Iraj, 2016), hence transforming students from passive listeners to active learners (Valizadeh & Soltanpour, 2020) and perform activities of higher order thinking (Al-Zoubi & Suleiman, 2021). As such, the in-class time learning environment is primarily dynamic, collaborative, and interactive (Zhu et al., 2020).

Several research was conducted to investigate the impact of the flipped classroom approach on students' learning and achievement across disciplines and educational levels. These include systematic reviews such as those of Özbay and Çınar (2021), Lencastre et al. (2020), Chen et al. (2017); scoping reviews conducted by O'Flaherty and Phillips (2015) and Tang et al. (2018); literature reviews of Akçayır and Akçayır (2018), Ward et al. (2018), DeLozier and Rhodes (2017), and Velegol et al. (2015); and meta-analyses by Strelan et al. (2020), Cho and Lee (2018), and Lo and Hew (2017).

Previous studies likewise revealed that the flipped classroom approach facilitated flexible, individualized, collaborative, interactive, and peer-based learning (Yuliyatno et al., 2019). It also promoted the acquisition of enhanced students' achievement and interest in learning (Shana & Alwaely, 2021; Al-Zoubi & Suleiman, 2021; Sudarmika et al., 2020), engagement (Ayçiçek & Yanpar Yelken, 2018) critical thinking (Listiqowati et al., 2022), problem-solving skills (Zain et al., 2022), and language competence (Valizadeh & Soltanpour, 2020; Girmen & Kaya, 2019). The approach enabled the teachers to maximize instructional time (Moraros et al., 2015), thus, earning positive feedback from students (Unal & Unal, 2017).

With the increased number of research studies conducted with the flipped classroom approach, several challenges, limitations, and gaps were exposed concerning its implementation. These include the lack of students' knowledge of how the flipped classroom approach works, considering that it is new for them (Van Sickle, 2016; DeSantis et al., 2015), the unprepared students for the in-class activities (Sahin et al., 2015), and lack of instructional design and theoretical framework for the implementation the approach (Lo & Hew, 2019). Regarding research methodology, some research gaps identified include using two groups of students with unequal prior knowledge (Hew et al., 2021; Chen et al., 2018). Strelan et al. (2020) also highlighted that some true experimental studies did not strictly follow the research design requirements. Additionally, there is a dearth of research studies in mathematics education that involve assessing and evaluating the proving competencies of students in a Finite Geometry class using the flipped classroom approach. Lo et al. (2017) opined that the First Principles of Effective Instruction could be a solid theoretical framework to guide the design for flipping mathematics classrooms at the higher education level.

The need to conduct a study in higher education that addresses these identified limitations and gaps is necessary to strengthen the available empirical evidence about the effects of the flipped classroom approach on students' achievement. The adherence to the requirements of a true experimental research design is vital to ascertain that the improved performances of students can be attributed to the intervention, in this case, the flipped classroom approach. Doing this can also guide future researchers in designing the methodology of their true experimental research studies. In addition, the current study utilized the First Principles of Effective Instruction as a framework for implementing the flipped classroom approach. The use of proving competencies as a measure of students' performances and the comparison of individual and group in-class scores of the flipped class are two noble aspects of the investigation that the current study offers, which are not found in the reviewed research studies on the flipped classroom. Also, the current study offers mathematics educators an additional instructional approach highlighting student-centredness and active learning that facilitates the development of students' problem-solving, critical thinking, and logical thinking skills, which are relevant to ascertain students' success in dealing with higher mathematics subjects. On the other hand, the study reflects an instructional approach that can help students receive the needed support from peers and teachers in the course of achieving the intended learning outcomes in mathematics in terms of the ability to derive proofs to given theorems.

Essentially, this study was conducted to address some gaps and limitations of previously conducted studies, such as students' unfamiliarity with the flipped classroom approach, the provision of a solid theoretical framework in the design and implementation of the approach, the use of the approach in mathematics subjects involving the creation of mathematical proofs, the dearth of true experimental studies for flipped versus non-flipped classrooms involving two equally-matched classes, and the comparison of students' performances in the flipped class in group and individual in-class activities. The study aimed to measure and compare the pretest and posttest scores in proving finite geometries theorems of the flipped and non-flipped classes, compare the in-class performances of the two classes, compare their post-test scores, and compare the scores of the flipped class in group and individual in-class activities.

Framework of the Study

Flipped Classroom

The flipped classroom approach comprises in-class activities consisting of interactive group learning activities inside the classroom and pre-class activities involving computer-based individual instruction outside the classroom (Khasanah & Anggoro, 2022). Essentially, the students learn the course concepts by watching video tutorials, usually at home; and the supposed homework in a traditional classroom is accomplished in the classroom (Sudarmika et al., 2020).

Abeysekera and Dawson (2015) enumerated three main features of the flipped classroom approach. First, it moves the acquisition and transmission of information to out-of-class activities. Second, the approach uses class time for active and social learning activities. Lastly, it requires students to complete learning activities during the actual class time.

Currently, there is no standard practice in implementing the flipped classroom approach (Lo & Hew, 2019; Lo, 2018; Ziegelmeier & Topaz, 2015). Lopes and Soares (2018) also reiterated that the approach has no standard model. One common feature of the flipped classroom structure utilized in the reviewed research articles was in terms of pre-class activities where lecture videos and other multimedia instructional materials were provided to students. For in-class activities, however, different research studies employed varied learning activities, most of which are group-oriented, allowing for student-centered, active, and small-group learning.

First Principles of Effective Instruction

One important consideration in applying the flipped classroom is to design its structure and implementation following a solid and robust instructional framework or model (Lo & Hew, 2019; Lo, 2018; O'Flaherty & Phillips, 2015). Merrill's (2017) First Principles of Effective Instruction is a potentially effective instructional framework for designing a flipped classroom approach (Lo, 2018; Lo et al., 2017). It was organized into four instructional phases - activation, demonstration, application, and integration. All these four phases are focused on problem-solving strategy.

The activation phase advocates the axiom of education: to start where the students are. Accordingly, learning is promoted when learners use their acquired knowledge as a foundation for learning new skills. Therefore, students should be directed to recall, relate, describe, or apply their previous knowledge from relevant experiences as foundations for learning new knowledge.

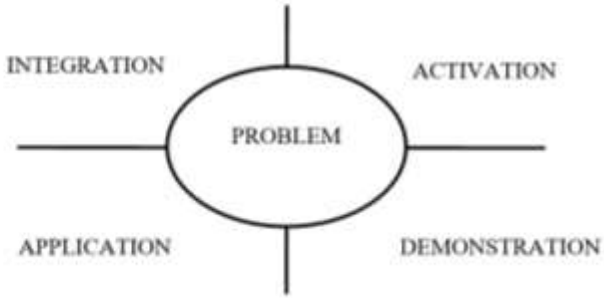

Figure 1
Phases for effective instruction (Merrill, 2017)

The demonstration phase captures Tell-Show learning events where the presentation of concepts was provided with sufficient examples. Teachers then must demonstrate new knowledge by providing illustrative examples and demonstrating appropriate procedures. On the other hand, students must be presented with further references and resources for further learning. In the application phase, the students are given opportunities to practice and apply their newly acquired knowledge by performing an academic task which includes problem-solving. To Merrill (2017), teachers should design and arrange problem-solving exercises of varied challenges sequentially. Lastly, the integration phase promotes students' deep learning through sharing, reflection, peer evaluation, and collaboration. The teaching and learning process must allow students to reflect on, discuss, defend, and apply their new knowledge or skills and must be given a chance to demonstrate their new knowledge or skills publicly.

Application of the Concepts to the Study

Two classes enrolled in Modern Geometry were utilized. For the flipped class, downloaded and researchers-made multimedia materials were made available to the students five days before the scheduled in-class session for each topic. Following the study of Arakaki (2017), the videos' length ranges from 3-10 minutes. Additionally, they were given hard copies of the target learning outcomes for each course content in finite geometries. Further, guide and reflective questions for self-assessment were distributed as part of the pre-class activities. Answers to the given questions were utilized to inform the researchers about the learning level of the students in relation to the learning outcomes before the actual class time. Lastly, Merrill's (2017) First Principles of Effective Instruction characterized the in-class session of the flipped class. The learning activities are student-centered. Apart from the paired or small-group activities, an individual assessment was also given toward the end of each topic.

METHOD

Research Design

This true experimental study employed the randomized pretest-posttest control group design using matched groups (Özçakır Sümen & Çalışıcı, 2022; Leppink, 2019;

Fraenkel et al., 2012). These classes were randomly assigned to either the flipped or non-flipped classes. To ensure equivalence in mathematical performances regarding proving skills in relation to the topics in finite geometries, the students were matched using the pretest results.

Procedure

The study was divided into two phases. The first phase included an informal interview to assess the students' awareness and readiness to undergo the flipped classroom approach. Then, the flipped class was given an orientation. The following week, a simulation was conducted of implementing the flipped classroom approach and the phases for effective instruction. This involved learning activities for both the pre-class and in-class sessions. After the simulation, the flipped class's readiness for the approach was assessed. The second phase consisted of the actual experiment that commenced with administering the pretest covering finite geometries topics - 3-point, 4-point, and 4-line geometries; finite geometries of Fano and Young; geometry of Pappus; and geometry of Desargues. Then, the flipped class students were grouped heterogeneously, each group with four to five members composed of respondents and non-respondents.

In the pre-class session, lecture videos, multimedia materials, learning outcomes, guide questions, practical and reflective questions, and other supplementary materials for each topic were provided to the students five days before the actual in-class session. Links to additional references were also provided. Their responses to the reflective questions informed the researchers in selecting, designing, and enhancing the in-class activities.

For the in-class session, the first hour was intended for the activation and demonstration phases, the second hour for the application and integration phases, and the third hour for individual activities. In the activation phase, the flipped class was assessed on their learning level, achievement of the learning outcomes, and experiences in their pre-class activities. The demonstration phase engaged the class in small-group to whole-class discussions to address difficulties raised during the activation phase and to strengthen their mastery of the needed competencies in proving theorems. The application phase involved small groups working on the given worksheets with items that measured proving skills. The integration required the students to present and/or defend their outputs. Lastly, each topic concluded with an individual learning activity and synthesis from the students and the researchers.

On the other hand, the teaching and learning process in the non-flipped class followed the traditional teacher-centered approach where students listened to the lectures delivered by the researcher, worked on exercises on the chalkboard, and accomplished individual in-class activities. The first meeting was allocated for teacher-led discussion, the second for individual assessment, and the third for checking outputs. At the end of the experiment phase, a posttest was administered to both classes.

Sources of Data

The two Modern Geometry classes served as respondents of the study. The classes are composed of 39 and 42 students who took the pretest. From the pretest results, the researchers identified 27 pairs of students that are matched or equivalent. The students who were not selected as respondents underwent the same teaching and learning process and accomplished the same activities. They were grouped with students identified as respondents of the study. However, the data needed to address the research objectives were collected from the identified 27 students from each class. All respondents indicated their willingness to participate through informed consent.

Data-Collection Instruments

The pretest-posttest instrument was carefully designed to consider the essential guidelines in preparing test items. Test items were based on the approved syllabus for Math 114 Modern Geometry based on the policies, standards, and guidelines of the Bachelor of Science in Mathematics curricular program. The pretest-posttest comprised four items for proving theorems, equivalent to 40 points or 10 points per item. For every topic, 20 points or equivalent to two items for proving theorems were provided for the in-class assessment activity. A rubric was used to evaluate the students' proofs. The rubric indicators included fluency in using the mathematics language, validity of assumptions, logical presentation of proofs using appropriate axiom/s, adherence to the rules of logic in forming deductions, and completeness and correctness of proofs (Brown & Michel, 2010). Two points were allocated for each indicator with the following scoring system: 0 – not evident, 1 – partly evident, and 2 – sufficiently evident. The set of axioms for each finite geometry was provided to the respondents.

The pretest-posttest and in-class activities underwent review by experts to establish their validity. The test instrument was found to be very highly valid, with a median rating of 5.0. Regarding reliability, the test instrument was pilot tested on 20 non-respondents who have already taken the course Modern Geometry. The analysis result showed a reliability coefficient of 0.84. Hence the test instrument is highly reliable.

Data Analysis

The performances of the flipped and non-flipped classes in the pretest and posttest were presented in terms of their actual scores. The average scores of the two classes in proving theorems were considered for the in-class activities. However, the flipped class's in-class performances were further categorized into two – group and individual.

The researchers compared the pretest and posttest scores of the flipped class, pretest and posttest scores of the non-flipped class, pretest scores of the two classes, posttest scores of the flipped and non-flipped classes, in-class performances in proving theorems of the two classes, and individual and group in-class performances of the flipped class.

Standard statistical procedures often require that the data be normally distributed. One of the assumptions for the *t*-test is normality (Ahmad & Khan, 2015). Hence, an exploratory data analysis (EDA) was conducted, and the results revealed that the data sets failed to satisfy the normality assumption. In cases where normality and other assumptions were not satisfied, the corresponding non-parametric tests were employed. From the EDA results, the statistical tools used were paired *t*-test, independent samples *t*-test, Wilcoxon Signed Rank Test, and Mann-Whitney U Test. The description for Cohen's d effect sizes as small ($d = 0.2$), medium ($d = 0.5$), and large ($d \geq 0.8$), as cited by Sullivan and Feinn (2012), were used in this study.

FINDINGS

Performance in the Pretest and Posttest

The pretest and posttest summary results are presented graphically in Figure 2. For the pretest, the proving skills of the non-flipped class garnered an average of 4.85 points, while a mean score of 4.7 points marked the performance of the flipped class. The graph of the pretest scores suggests comparable performances in proving theorems between the two classes. In the posttest, however, the flipped class remarkably increased its performance by 11.52 points, while only 0.26 points for the non-flipped class. Generally, the flipped class recorded a 300% performance enhancement, while the non-flipped class recorded a 5% improvement.

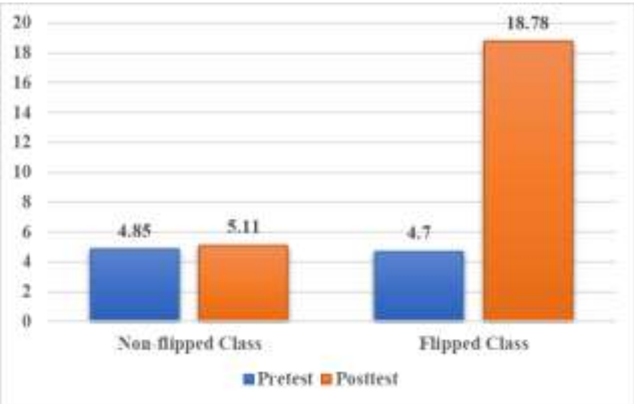

Figure 2
Performances of the Flipped and Non-Flipped Classes

Comparison of Pretest and Posttest Performance

The pretest and posttest scores of the two groups were compared to check if significant differences existed between their proving competencies. Table 1 reveals that before the experiment, the performances in proving theorems of the flipped and non-flipped classes do not have a statistically significant difference as viewed from the Mann-Whitney U Test results, [χ^2(54)=321.50, *p*=0.43].

Table 1
Comparative analysis of pretest and posttest performances

Test	Class/Pair	Statistical Computed Value (df)	p-value	Effect Size
Pretest-Posttest	Non-Flipped Class	70.00 (27)	0.052	
Pretest-Posttest	Flipped Class	-14.07 (26)**	< 0.01	3.89
Pretest	Non-flipped - Flipped	321.50 (54)	0.430	
Posttest	Non-flipped - Flipped	729.00 (54)**	<0.01	3.340

**significant at 0.05

Meanwhile, the Wilcoxon Signed Rank Test results suggest no statistically significant difference between the pretest and posttest performances of the non-flipped class, [$W(27)=70.00$, $p=0.052$]. Thus, no remarkable improvement was noted in the ability of the non-flipped class to generate valid and logical proofs of the theorems in finite geometries. Additionally, the paired *t*-test for the flipped class shows that the observed differences between the means of the pretest and posttest scores in proving competencies [$t(26)=-14.07$, $p<0.01$] are statistically significant. The effect size of 3.89 verifies that the flipped class significantly improved their posttest scores. Lastly, the between-groups comparison using the Mann-Whitney U Test, [$\chi^2(54)=729.00$, $p<0.01$], confirms that there is a statistically significant difference between the posttest performances of the two classes. The flipped class outperformed the non-flipped class. The effect size of 3.340 provided a substantial indication that the intervention applied in the experiment was effective.

Comparisons of Performances in In-class Activities

Table 2 exhibits the comparison results for the proving competencies of the flipped and non-flipped classes in the in-class activities and for the individual and group in-class performances of the flipped class using the *t*-test and Wilcoxon Signed Rank Test.

Table 2
Comparative Analysis of the In-class Performances

Class/Pair	Statistical Computed Value (df)	p-value	Effect Size
Non-Flipped Class vs. Flipped Class	-20.04 (52) **	<0.01	5.453
Flipped Class (Group vs. Individual)	-1.39 (26)	0.177	

**significant at 0.05

Accordingly, a statistically significant difference was found along the scores of the two classes in writing logical and rational proofs of theorems in finite geometries, [$t(52)=-20.04$, $p<0.01$]. Furthermore, the effect size of 5.453 confirms that the flipped class exhibited higher scores and indicated better performances in the learning activities provided during the in-class sessions. Overall, these findings suggest the effectiveness of the flipped classroom approach in developing students' critical thinking, problem-solving, and logical thinking skills. Further analysis revealed no statistically significant differences in the flipped class group and individual in-class activity scores, [$t(26)=-1.39$, $p=0.177$]. The result suggests that the flipped class demonstrated equivalent performances regardless of whether these activities were accomplished in small groups or individually.

DISCUSSION

The findings of this true experimental study indicated that the flipped class outperformed the non-flipped class in proving theorems. The significant increase in the posttest scores of the flipped class and the class's equivalent performances in individual and group activities proved the positive impact on the learning achievement of the flipped classroom with the First Principles of Effective Instruction. These findings can be attributed to various conceptual and theoretical underpinnings as provided in the framework of the study.

Firstly, the flipped classroom approach allowed the students to learn and gain vital information about the topics through the materials provided prior to the in-class time. Consequently, the in-class time was devoted to engaging students in student-centered learning activities. These highlighted the activation phase of effective instruction.

Secondly, consistent with the demonstration and application phases of instruction, the flipped class was given opportunities to take responsibility for their learning while receiving guidance and feedback from their teacher and the needed support from their peers. The approach also activated peer-assisted learning, as most in-class sessions required group discussions and student interaction. Whenever needed, the teacher provided illustrative examples and demonstrated relevant procedures for proving theorems in finite geometry. Then, the students were directed to practice their new knowledge and skills by working on the given activities.

Thirdly, the integration phase of instruction capitalized on students’ active learning through sharing, reflection, peer evaluation, and collaboration. Opportunities for students to present, reflect on, defend their answers and proofs, or critique the works of their peers were the highlights of these in-class activities.

Lastly, the digital and audio-visual components of the approach also contributed to the flipped class's active learning engagement and improvement. Students provided with digitally-recorded pre-class lectures tend to be more prepared for the in-class activities, better understand the subject matter, and develop critical thinking skills, given that the materials can be studied repeatedly.

The current study emphasizes some noble aspects of conducting research in instructional pedagogies, particularly the flipped classroom approach, as it addressed the gaps found in previously conducted research studies. First, this study ensured adherence to the requirements of true experimental research, which is necessary to ascertain that the intervention causes the differences in the performances of the respondents. Second, as students’ engagement using an instructional approach is vital in delivering quality instruction, the simulation phase of the study provided enough preparations and guidance for the students, which contributed to the smooth implementation of the flipped classroom approach following the different phases of instruction. Third, the reviewed research studies noted the lack of a framework for utilizing the flipped classroom approach. Such was addressed in this study through the implementation of the First Principles of Effective Instruction, which provided the needed systematic and solid instructional framework for implementing the in-class sessions of the approach. The use of proving competencies as a measure of performance distinguishes the current study from the existing related studies in mathematics education. Lastly, while most related studies only considered between-groups comparisons using the respondents’ individual scores, this study also compared the flipped class's individual and group in-class scores.

Meanwhile, several study limitations are observed, which can open potential topics for a scientific investigation. First, the current study focused on the cognitive attributes of the respondents. It is noteworthy to investigate also the effect of the flipped classroom approach on the affective attributes such as students' engagement and satisfaction. Also, the study covered only a single unit of the Modern Geometry course. Conducting a study with a longer duration involving all course topics can potentially establish patterns about the impact of the approach on students' learning achievement. Lastly, the First Principles of Effective Instruction was solely used to support the instructional delivery design in the in-class sessions of the flipped class.

CONCLUSIONS

Generally, the flipped class exhibited higher learning gains and significant improvement in mathematical knowledge, particularly in proving theorems, which is vital in learning finite geometries. Within the context of true experimental research, students in the flipped class demonstrated equivalent performance in individual and group in-class activities. With the integration of Merrill's First Principles of Effective Instruction, the flipped classroom approach provided a platform for active learning to prosper inside the classroom, which benefitted the flipped class regarding conceptual learning, critical thinking, problem-solving, and logical thinking.

The study's results strengthened the positive impact of the flipped classroom on the students' learning gains and achievement. It provided research-based evidence that the students in the flipped class indicated more significant improvement in mathematical skills and competencies in proving theorems than those in the traditional classroom. When used with a solid instructional framework, the flipped class will likely perform equivalently regardless of whether the activities are done individually or by groups.

To deepen the available literature regarding the flipped classroom approach, researchers are encouraged to replicate the study involving all disciplines across educational levels to establish substantial research-based evidence on the significant impact of the approach on students' learning achievement. Researchers may consider exploring the impact of the approach on students' affective development by conducting a qualitative study that can uncover the remarkable experiences of students taught with the approach. Other instructional frameworks to support the in-class sessions of the flipped classroom approach can be used, such as the 5E, 7E, or 3I models. A study using the approach in a full-online learning environment can also be conducted.

Finally, reflecting on the empirical evidence derived from this true experimental study, the study recommends exploring the utilization of the flipped classroom approach in ensuring continuous delivery of quality instruction to students considering the current global situation due to COVID-19. Instructional leaders can integrate the use of the flipped classroom approach as one of the various learning modalities that support the concepts of online learning, flexible learning, and digital learning in their academic plan or learning continuity plan as an adaptive response to the demands of education in terms of adaptability, flexibility, and inclusivity during the post-pandemic or recovery period and beyond.

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