ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1477

The Effectiveness of the Flipped Classroom Approach in Enhancing Grade 10 Students' Achievement in Learning Radicals: A Quasi-Experimental Study at Jakar Higher Secondary School, Bhutan

Sonam Phuntsho; Yeshi Dorji

Publication Date: 2026/09/12

Abstract: This action research examined the effectiveness of a Flipped Classroom Approach (FCA) in improving Grade 10 students' achievement in learning radicals at Jakar Higher Secondary School, Bhutan. A mixed-methods design was adopted, combining quantitative evidence from an achievement test with qualitative insights obtained through semi-structured interviews. The participants comprised (n=23) Grade 10 students. An 18-item Mathematics Achievement Test (MAT), with a maximum score of 25, was administered before and after the intervention. In addition, two students were interviewed to obtain their perspectives on the learning experience. As part of the intervention, students accessed recorded instructional lessons and supporting materials prior to classroom sessions. Classroom time was subsequently devoted to guided problem-solving, discussion, feedback, and clarification of mathematical concepts. Data were analysed using descriptive and inferential statistics in SPSS, including a paired-samples t-test. The results showed an increase in the mean MAT score from (M=5.70) before the intervention to (M=12.00) after the intervention, representing a mean improvement of (M=6.30) points. This improvement was statistically significant, $t(22)=18.80$, $p<.001$. Qualitative findings further revealed that students appreciated being able to revisit recorded lessons, receive additional assistance from the teacher, and engage more actively in classroom learning. Nevertheless, difficulties related to access to digital devices and effective management of learning time were reported. Overall, the findings indicate that FCA may serve as a useful supplementary approach for teaching radicals in mathematics, particularly when students have adequate access to learning resources and receive appropriate classroom support.

Keywords: *Flipped Classroom Approach (FCA), Academic Performance, Mathematics Achievement Test, Radicals.*

How to Cite: Sonam Phuntsho; Yeshi Dorji (2026) The Effectiveness of the Flipped Classroom Approach in Enhancing Grade 10 Students' Achievement in Learning Radicals: A Quasi-Experimental Study at Jakar Higher Secondary School, Bhutan. *International Journal of Innovative Science and Research Technology*, 11(8), 3497-3505. https://doi.org/10.38124/ijisrt/26aug1477

I. INTRODUCTION

Teachers continually make decisions about how mathematical content should be presented, practised, and assessed in order to support students' learning. Educational research provides a means of examining these decisions systematically and using classroom evidence to guide instructional improvement. Action research is particularly relevant to this process because it enables teachers to investigate issues arising from their own practice, interpret evidence generated in the classroom, and make informed decisions about subsequent teaching (Koshy, 2005; Whitehead & McNiff, 2006). Rather than treating instructional approaches as universally effective, action research allows practitioners to consider whether a particular approach responds appropriately to the needs and circumstances of their learners.

The need for effective instructional practices is especially important in mathematics education. Mathematical proficiency extends beyond the ability to recall formulas or follow predetermined procedures. Learners are expected to understand mathematical concepts, recognise relationships among different representations, communicate their reasoning, and apply previously learned knowledge when encountering unfamiliar situations. Consequently, teachers need to create learning environments in which students have sufficient opportunities to explore ideas, practise mathematical procedures, discuss their reasoning, and receive feedback. The Royal Education Council (2018) has highlighted the importance of reflective

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1477

and responsive teaching in Bhutan, while earlier national reports have drawn attention to issues associated with student learning and educational achievement (Royal Education Council & Educational Initiatives, 2009, 2010).

These concerns are also reflected in the academic performance of Bhutanese students. Lhamo (2022) reported a notable decrease in the Class X pass rate and identified mathematics as an area requiring particular attention. Such evidence suggests a need to examine instructional practices that can provide students with more meaningful opportunities to engage with mathematical content. In particular, approaches that allow students to spend classroom time working through mathematical problems with teacher guidance may provide opportunities to address conceptual misunderstandings and strengthen procedural knowledge.

The flipped classroom approach (FCA) offers one possible way of reorganising classroom learning. In a conventional lesson, the teacher commonly introduces new content during face-to-face instruction, while students are expected to complete practice activities independently outside school. In contrast, a flipped classroom moves some initial content exposure to the period before the classroom lesson, often through recorded explanations, readings, or other teacher-prepared resources. Classroom sessions can then be used more extensively for problem-solving, guided practice, collaborative activities, discussion, and feedback (Bergmann & Sams, 2012, 2014; Hamdan et al., 2013). The distinctive feature of FCA, therefore, is the purposeful redistribution of learning activities rather than the mere introduction of technology into teaching. Previous studies have reported potential benefits associated with this approach, including greater flexibility in accessing instructional materials, increased student participation, and more productive use of face-to-face classroom time (Baepler et al., 2014; Kim et al., 2014; Strelan et al., 2020).

Despite these potential benefits, the implementation of FCA should be considered in relation to the educational context in which it is introduced. A flipped learning model may depend on students having reliable access to digital devices, internet connectivity, and appropriate learning resources outside scheduled classroom hours. Such conditions cannot necessarily be assumed for all learners in Bhutan. Previous Bhutanese studies have reported encouraging student responses to flipped learning while also identifying difficulties associated with access to technological devices and digital resources (Jurmey et al., 2019; Dorji & Dorji, 2022). These findings indicate that successful implementation requires adaptation to the circumstances of individual schools and learners. In contexts where access is uneven, teachers may need to provide alternative learning materials and additional classroom support to ensure that the approach does not disadvantage students with limited technological access.

The topic of radicals provides a relevant context for examining this instructional approach. Learning radicals requires students to understand and apply several interconnected mathematical procedures, including simplifying radical expressions and performing operations involving radicals. Students who have difficulty understanding the underlying concepts may rely heavily on memorised procedures, which can make it challenging to apply their knowledge to unfamiliar problems. Providing students with opportunities to encounter explanations before class and subsequently work through problems with teacher guidance may create additional opportunities to clarify misconceptions and strengthen understanding.

The present action research was conducted at Jakar Higher Secondary School, Bhutan, where the researcher teaches mathematics. The school has engaged in professional learning activities and has been affiliated with the Bhutan Baccalaureate and Druk Gyalpo's Institute since 2021. This environment provided an appropriate setting for investigating a learner-centred instructional approach within an authentic classroom context. The study focused on Grade 10 students' learning of radicals and examined changes in their achievement following the implementation of FCA. The investigation was intended not only to determine whether students' achievement improved following the intervention but also to understand students' experiences of learning through the flipped model. The findings are expected to provide classroom-based evidence on the potential usefulness of FCA as a supplementary approach to mathematics instruction and to identify practical considerations for its implementation in the Bhutanese school context.

- *Aims of the Study*

The study aimed to examine the effectiveness of the Flipped Classroom Approach in enhancing Grade 10 students' achievement in learning radicals.

II. RECONNAISSANCE

- *Situational Analysis*

Education in Bhutan has undergone a gradual transformation from its historical foundations in monastic education to the development of a formal modern schooling system (Wangmo & Choden, 2010). Alongside this transformation, educational reforms have increasingly focused on developing learners as active participants in their own learning and supporting their intellectual, personal, and social development. This direction has encouraged teachers to reconsider predominantly teacher-directed classroom practices and provide learners with greater opportunities to participate, make decisions, and take responsibility for their learning (Rabgay, 2018; Saulnier, 2009).

The Flipped Classroom Approach (FCA) provides one possible way of supporting this learner-centred orientation. Under this approach, students are introduced to selected learning materials before the scheduled classroom lesson, allowing face-to-face sessions to place greater emphasis on application, discussion, problem-solving, and teacher-guided practice. Recorded explanations can also allow students to control the pace of their initial learning by pausing, replaying, and reviewing difficult sections when necessary.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1477

At the same time, the effectiveness of such an approach depends on students having reasonable access to learning resources and developing the ability to complete preparatory learning independently.

Jakar Higher Secondary School is situated approximately 269 kilometres from Thimphu, opposite Jakar Dzong in Bumthang. The school has demonstrated achievement in academic and other areas and has been associated with the Bhutan Baccalaureate and Druk Gyalpo's Institute since 2021. Teachers at the school have also engaged in professional learning activities related to the Bhutan Baccalaureate. This professional context provided an appropriate foundation for the researcher to examine an instructional approach intended to increase students' active involvement in mathematics learning and make classroom interaction more purposeful.

- *Competence*

The researcher is a mathematics teacher at Jakar Higher Secondary School and holds a Master of Education in Mathematics from Samtse College of Education, Bhutan. The researcher's postgraduate academic experience included an investigation of cooperative learning in mathematics, providing prior exposure to classroom-based research and the examination of instructional interventions. In addition, the researcher participated in mathematics curriculum review activities facilitated through the Department of Curriculum and Professional Development. These academic and professional experiences contributed to the researcher's capacity to plan and conduct classroom-based inquiry.

A competent action-research team member was also involved in supporting the implementation of the intervention and the collection of research data. The involvement of another team member provided additional support during the research process and contributed to the systematic implementation of the study procedures.

III. LITERATURE REVIEW

Flipped learning has emerged as an instructional model within blended learning in which students are introduced to learning content before attending face-to-face lessons, while classroom sessions are used for activities requiring greater interaction between teachers and learners (Pinelli & Fiorucci, 2015). Bergmann and Sams (2012) explain that the approach reorganises the conventional sequence of instruction by providing students with access to explanations and preparatory resources before class and using classroom time for teacher-supported learning activities. Consequently, the central purpose of flipping a classroom is not merely to replace face-to-face lectures with recorded videos but to reconsider how limited classroom time can be used to promote deeper engagement and learning.

In practice, FCA involves two interconnected stages of learning. Before the classroom session, students may engage with teacher-created videos, readings, notes, or other preparatory resources and complete tasks designed to establish an initial understanding of the topic. The subsequent classroom session can then focus on applying knowledge, solving problems, discussing ideas, addressing misconceptions, and receiving individual or group support from the teacher. Brame (2013) argues that effective flipped learning requires students to be adequately prepared before class, while classroom activities should provide meaningful opportunities for active engagement and mechanisms for maintaining students' responsibility for their preparation.

An important potential advantage of FCA is the flexibility it provides during the initial stage of learning. Unlike a single classroom explanation, recorded instructional material can be accessed repeatedly according to individual learning needs. Students who do not understand a particular explanation can pause or replay the relevant section and review accompanying materials before attempting classroom activities. Jeong et al. (2016) found that students' views of flipped learning were associated with characteristics of their learning environment, while Kim et al. (2014) identified several design considerations that may contribute to effective implementation of flipped instruction. Such flexibility can be valuable in mathematics, where students often require different amounts of explanation, demonstration, and practice before they can apply a concept independently.

Research conducted across different educational settings has reported several potential benefits associated with flipped learning. These include improvements in academic achievement, learner engagement, satisfaction, and perceptions of the learning process, although outcomes are influenced by the manner in which the approach is designed and implemented (Jurmey et al., 2019; Zainuddin & Attaran, 2016). In a broader synthesis of research evidence, Strelan et al. (2020) found that flipped instruction can have a positive influence on student performance across different educational contexts. Nevertheless, variations in study design, subject area, learner characteristics, and implementation conditions indicate that the effectiveness of the approach should be examined within particular educational settings rather than assumed to be uniform.

Despite its potential benefits, FCA presents practical challenges that may affect students' participation and learning. Because part of the learning process takes place outside the classroom, students need to allocate time effectively, access the required instructional resources, and complete preparatory activities with an appropriate level of independence. Limited access to digital devices or reliable internet connectivity can further restrict students' ability to participate fully in pre-class learning. In Bhutan, Dorji and Dorji (2022) reported challenges associated with access to computers and internet-based resources in a school context. These concerns are particularly relevant to the present study because the intervention was implemented under the actual technological and educational conditions of a Bhutanese secondary school rather than in a setting where unrestricted digital access could be assumed.

The existing literature indicates that the effectiveness of flipped learning is influenced by the context, design of

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1477

learning activities, and support provided to students. This provides a rationale for investigating the approach within specific classroom environments and educational settings. The present study addresses this need by examining FCA in Grade 10 mathematics at Jakar Higher Secondary School, Bhutan, with particular attention to the topic of radicals.

Radicals constitute an important area of mathematics because students are required to interpret mathematical notation, simplify radical expressions, perform operations involving radicals, and apply appropriate procedures when solving problems. Difficulties in any of these areas can affect students' ability to solve increasingly complex mathematical tasks. Providing students with access to instructional explanations before class and using classroom time for guided practice and clarification may therefore offer opportunities to address learning difficulties more directly.

In addition to examining changes in students' achievement, the present study considers students' experiences of the flipped learning process. Combining achievement evidence with students' perspectives provides a broader basis for evaluating the intervention and identifying practical factors that may influence its implementation. The study consequently seeks to contribute classroom-based evidence on the applicability of FCA to Grade 10 mathematics, particularly the teaching and learning of radicals, within the Bhutanese secondary-school context.

➢ *Research Question*

How effective is the Flipped Classroom Approach in improving Grade 10 students' achievement in learning radicals?

IV. METHODOLOGY

➢ *Research Design*

The study used an action-research framework with a mixed-methods design. Quantitative data were collected through a Mathematics Achievement Test before and after the intervention, and qualitative information was obtained through semi-structured interviews. The quantitative component used a one-group pre-test-post-test quasi-experimental design. Because the same students completed both assessments, the analysis focused on change in achievement from baseline to post-intervention rather than comparison with a separate control group. Qualitative interview data were used to provide contextual information about students' experiences of the flipped lessons (Creswell, 2012, 2014).

➢ *Participants and Sampling*

The population consisted of 116 Grade 10 students across four sections (A, B, C, and D). Section B was selected purposively because its mathematics performance was comparatively weak. Twenty-three students from the section participated in the study, comprising 10 boys and 13 girls. The intervention was conducted over two weeks, with four 50-minute periods per week. Two students subsequently volunteered for the semi-structured interviews.

➢ *Research Instrument*

The quantitative instrument was a Mathematics Achievement Test consisting of 18 questions with a maximum score of 25. The test was used for both pre-test and post-test measurement. Senior teachers and a mathematics lecturer from Samtse College of Education reviewed the instrument for content appropriateness. A pilot administration was used to examine internal consistency, and Cronbach's alpha was reported as 0.78, indicating acceptable reliability for the study. The qualitative instrument was a semi-structured interview conducted after the post-test to explore students' perceptions of the flipped classroom and their experiences with the learning process.

Table 1 Pre-Test and Post-Test Design (One-Group)

Group	Pre-test	Treatment	Post-test
1	01	A Flipped Classroom Approach (FCA)	02

➢ *Intervention*

Before the flipped intervention, students were taught the topic without the flipped approach. A pre-test was then administered to establish baseline achievement. For the intervention, the researcher introduced recorded video lessons and supporting learning materials as pre-class resources. Because not all participants had reliable access to a computer or smartphone at home, arrangements were made for students to use the school's Information Technology laboratory to view the videos and review the materials. Classroom sessions were then used for guided practice, discussion, clarification of difficult concepts, and other learning activities. The post-test was administered after completion of the intervention.

The instructional time was also recorded. The conventional phase required 11 periods, or 550 minutes, to cover the specified learning content. The flipped intervention required 8 periods, or 400 minutes. Thus, the recorded difference was 150 minutes. This time comparison was treated as a description of instructional use rather than as an independent measure of learning effectiveness.

➢ *Data Analysis*

Quantitative data were analysed using SPSS version 22. Descriptive statistics were used to summarize the achievement-test results, while a paired-samples t-test was used to examine the difference between pre-test and post-test scores. The assumption of approximate normality was considered using skewness and kurtosis. The interviews were transcribed and examined thematically to identify

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1477

recurring views about the usefulness, advantages, and challenges of the flipped approach. The qualitative findings were used to complement the quantitative results rather than to replace the statistical analysis.

V. FINDING AND DISCUSSION

❖ *Descriptive Statistics of the Mathematics Achievement Test (MAT)*

➢ *Normality Test*

The *normality tests* were used to determine if sample data are normally distributed. Since the sample size was less than 50 in each section, Skewness and Kurtosis statistics and histograms were used to assess the normality of the distribution of the test scores. Skewness and Kurtosis statistic table and histograms related to the pre-test and post-test scores of the group. The descriptive statistics of the scores given (Table 2), is the value of the Skewness and Kurtosis scores' distribution between -1.96 and +1.96. Thus, it can be concluded that the pre-test and post-test scores of the group (01 and 02) were normally distributed.

Table 2 Descriptive Statistics Normality data of the Group

	N	**Mean**	**Std. Dev.**	**Skewness**			**Kurtosis**	
	Stat	Stat	Std. Err	Stat	Stat	Std. Err	Stat	Std.Err
Pre-test	23	5.70	.37	1.77	.24	.48	-.79	.94
Post-test	23	12.00	.34	1.62	-.49	.48	-.17	.94

Similarly, as the result Table 3 showed that the flipped classroom intervention significantly was higher than the traditional: [t (18) = 18.805, p=.006<0.05, a pre-test ($\bar{x}$=5.70), post-test ($\bar{x}$=12.00) and mean difference of ($\bar{x}$=6.30)]. The result was obtained from the paired sample t-test on the achievement test. Therefore, the overall results showed that flipped classrooms approach outperformed the traditional teaching on Mathematics achievement tests.

Table 3 Descriptive Statistics of the Mathematics Achievement Test (MAT)

		N	**M**	**MD**	**SD**	**SD Err.**	**t**	**Sig (2 Tailed)**
Pair 1	Pre-test	23	5.70	6.30	1.60	.33	18.81	.006*
	Post-test	23	12.00					

Significance level of p=*.006** < 0.05

The *paired sample t-test* at a 95% confidence interval was conducted to compare the pre-post-test within the group. It is evident from Table 4 that the value between the Pre-test and Post-test in MAT is 18.805. It is significant at the .001 level for the df 22. Hence, the null hypothesis stated is rejected. The mean score difference of 6.304 inferred that the Flipped Classroom approach to Radicals and the Operation of Radicals in the Mathematics Unit has positively affected the students' achievement in Mathematics.

Table 4 Paired Samples Test of the MAT for pre-test & post-test

		Paired Differences					**t**	**df**	**Sig. (2-tailed)**
		M	***SD***	***SD* Err. Mean**	**95% Confidence Interval of the Difference**				
					Lower	**Upper**			
Pair 1	Pre-test & Post-test	6.30	1.61	.34	7.0	5.61	18.80	22	.001

Table 5 shows the total instructional time recorded for coverage of the whole lesson. The time taken to complete the specified topic is lesser in the treatment group. The time difference of 150 minutes. The lesson was taught for 50 minutes per period in the class at their own pace.

Table 5 Instructional Time Engaged by Each Group (Minutes)

	Number of the Period Recorded	**Total Time (Minutes)**
Conventional (pre-test)	11 periods	550 (50 per period)
Treatment FCA (post-test)	8 periods	400 (50 per period)

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1477

➢ *The Semi-Structured Interview*

Semi-structured *face-to-face interviews* were analyzed to corroborate and affiliate the quantitative data responses to the achievement test. The interview helps the researcher to collect in-depth and meaningful information (Merriam, 2009). The two participants from the group volunteered for an interview. The interview took about 16 minutes for each participant.

The interview was audio recorded with the student. The audiotapes were played back several times and transcribed to facilitate data analysis. The student participants were coded as S1 and S2 to maintain the confidentiality. The data transcriptions were based on their responses. A total of three themes were identified - students' opinions towards using the FCA, its advantages, and challenges.

Correspondingly, the study based on semi-structured interview data revealed that the FCA was found to be fostering a positive learning environment. Participants S1 and S2 shared a similar opinion about the experience of FCA learning by watching videos and could complete homework in the classroom. The participants wished to have the same teaching approach and recommended to use FCA in other subjects. Further, S1 shared his experience of attending FCA class:

I feel we are engaged thoroughly in the FCA by watching video lessons. I like working with my team to know more. I feel more secure and confident in learning at FCA. With the help of video lessons, I could complete my homework on time in the classroom.

The second theme is the advantages of flipped lessons. The participants view that they learned better from teachers using FCA pedagogy. For instance, S2 stated that,

"I could Google or browse better conceptual understanding from the internet and discuss with friends."

She found that she could learn better during the free hours. She benefited from spending her time watching the video lessons in the ICT lab. Additionally, a similar view was expressed by S1

It would be good for us if teachers use this FCA in teaching lessons. In traditional teaching, I feel exhausted and do not like to attend. I do not get time to rewind and revisit the lessons. I prefer FCA because I could watch the video lessons again till I learned all the concepts.

The third common theme is the challenges in the flipped classroom. Both the participants shared their difficulty managing time in FCA. For example, S2 specified, "Effective time management is not easy for some of us, but everyone felt it is important to develop habits to improve their time management skills". Besides the challenges, S1 added, "The problem that we faced was the lack of necessary materials such as earphones and enough working computers in the school".

VI. DISCUSSION

➢ *Mathematics Achievement Test*

The 23 students obtained a mean score of 5.70 on the pre-test and 12.00 on the post-test. The mean improvement was therefore 6.30 marks. A paired-samples t-test indicated that the increase was statistically significant, $t(22)=18.80$, $p<.001$. The result indicates a substantial improvement in students' achievement after the flipped intervention. Importantly, because the study used a one-group pre-test-post-test design, this result should be interpreted as evidence of improvement following the intervention rather than definitive proof that the flipped approach alone caused the improvement.

The achievement finding is broadly consistent with earlier research reporting positive outcomes from flipped instruction. Jurmey et al. (2019), for example, found favourable achievement and attitudinal outcomes in a Bhutanese secondary-school context. Other studies have similarly reported that flipped learning can support achievement by giving students access to preparatory materials before class and creating more opportunities for active work during the lesson (Brunsell & Horejsi, 2013; Zappe et al., 2009). The present finding adds a mathematics-specific example from Grade 10 students learning radicals.

One possible explanation for the improvement is the additional opportunity to encounter the content before class and then practise it with teacher support. Students could revisit recorded explanations when necessary, while classroom time was used to work through difficulties. This arrangement may have helped students connect procedural explanations with guided practice. However, the improvement may also reflect other factors associated with repeated exposure to the topic and completion of a pre-test, so causal conclusions should remain appropriately cautious.

➢ *Students' Experiences of the Flipped Classroom*

The interviews identified three broad themes: students' views of the learning experience, perceived advantages of flipped lessons, and challenges associated with the approach. Both interviewed students described the flipped lessons positively and indicated that the videos helped them engage with the content. One participant explained that watching the lessons and working with peers helped them feel more secure when learning in the flipped environment. The students also expressed interest in using a similar approach in other subjects.

The second theme concerned the flexibility of the learning materials. Students valued being able to revisit a video and use available time to review concepts. This observation is consistent with the literature suggesting that flipped learning can provide learners with greater control over the pace of initial content exposure (Bergmann & Sams, 2014; Jeong et al., 2016). In the present study, the opportunity to use the school ICT laboratory was particularly important because not every student had suitable digital resources at home.

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The third theme was the difficulty of managing time and accessing resources. Students indicated that independent learning requires discipline and that effective time management is not automatic. One participant also pointed to limitations involving devices and computer access. These comments reinforce the importance of digital equity in flipped learning. A flipped classroom should not assume that all students can complete pre-class activities under identical conditions. Where access is limited, schools may need to provide printed materials, scheduled ICT-lab access, or other alternatives.

- *Instructional Time*

The study recorded 11 periods, or 550 minutes, during the conventional phase and 8 periods, or 400 minutes, during the flipped phase. The flipped intervention therefore used 150 fewer minutes for the specified content. Similar observations have been reported in research examining the use of class time in flipped environments (Baepler et al., 2014; Smith, 2013). Nevertheless, reduced instructional time should not be treated automatically as evidence of superior learning. The educational value of the time depends on whether students are adequately prepared and whether classroom activities make productive use of the available period.

Overall, the quantitative and qualitative findings point in the same direction. Achievement increased after the intervention, and the interviewed students described the flipped lessons as useful and engaging. At the same time, the findings show that successful implementation depends on access to learning resources, student self-management, and teacher support. These contextual factors are particularly relevant for Bhutanese schools where learners may have different levels of access to digital devices and connectivity.

VII. CONCLUSION

This action research investigated the application of the Flipped Classroom Approach (FCA) in teaching radicals to Grade 10 students at Jakar Higher Secondary School. The findings demonstrated a clear improvement in students' mathematics achievement following the intervention. The average score increased from 5.70 in the pre-test to 12.00 in the post-test, yielding a mean difference of 6.30 marks. The paired-samples t-test indicated that the observed change was statistically significant, $t(22) = 18.80$, $p < .001$. Evidence from the student interviews provided additional insight into this outcome. The participating students reported that access to recorded instructional materials enabled them to revisit explanations, while classroom sessions provided opportunities to practise mathematical tasks, interact with the teacher, and seek assistance when difficulties arose.

The findings indicate that FCA has potential as a supplementary approach to mathematics instruction when its implementation is aligned with learners' needs and the available resources. The value of the approach appears to extend beyond the provision of recorded lessons. Its main pedagogical contribution lies in reorganising when and how learning activities occur, allowing students to obtain initial explanations before classroom sessions and use face-to-face instructional time for guided problem-solving, mathematical discussion, feedback, and conceptual clarification. However, the successful implementation of this model requires attention to practical factors, particularly students' access to appropriate learning resources and their capacity to organise their time and complete preparatory activities.

Several limitations should be considered when interpreting the findings. The study was conducted with 23 students from a single Grade 10 section, which limits the extent to which the findings can be transferred to other groups or educational settings. Furthermore, the one-group pre-test–post-test design did not include a comparison group; therefore, the observed improvement cannot be attributed exclusively to FCA with the same level of confidence that would be possible in a controlled experimental design. The duration of the intervention was also limited, and qualitative evidence was obtained from only two students. These factors restrict the generalisability of the findings and highlight the need for further investigation. Future research could strengthen the evidence base by involving larger samples from different schools, extending the duration of the intervention, incorporating comparison or control groups, and examining additional outcomes such as long-term retention, learner engagement, conceptual understanding, and mathematical reasoning.

From a classroom perspective, the findings provide preliminary support for incorporating FCA as a supplementary teaching strategy in mathematics, particularly for topics that require repeated explanation and extensive practice, such as radicals. Teachers implementing the approach may consider providing concise and purposeful preparatory materials before lessons and using classroom sessions primarily for problem-solving, guided practice, feedback, and addressing individual misconceptions. In contexts where students have limited access to personal digital devices or reliable internet services, schools may consider alternatives such as shared devices, scheduled ICT-laboratory access, or printed and offline learning materials. Such adaptations can help make the approach more responsive to local conditions and ensure that the benefits of flipped learning are not dependent solely on students' access to technology.

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