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Research article

Beyond the conventional flipped classroom: Exploring the efficacy of the 5I model of flipped learning in senior secondary school mathematics

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Abstract: In most African nations, including Nigeria, the persistent underperformance of students in mathematics is largely attributed to the effectiveness of the instructional delivery. Research has shown that the flipped classroom is an effective strategy for enhancing students' understanding and engagement in mathematics. However, earnest efforts to effectively adapt the flipped classroom strategies to an African context, where infrastructural and motivational barriers present notable challenges, remain a palpable gap in the literature. This study explored the effectiveness of a flipped model structure—the 5I model of the flipped classroom—in improving mathematics learning outcome of senior secondary school students in Nigeria. The 5I model consists of five phases of learning activities: Immerse, Interact, Illustrate, Illuminate, and Incentivize. An explanatory sequential design involving quasi-experimental and interview phases was adopted for this study. A total of 208 senior secondary two (SS2) students from conventional flipped classrooms (control group) and 5I model flipped classrooms (experimental group) participated in the study. The results show that the 5I model significantly improves the students' mathematics achievement, scaffolding engagement, knowledge retention, and deep inquiry skills among the students. Within the limitations of the study, it was concluded that the 5I model is a viable approach for effectively implementing the flipped model in mathematics classrooms in Lagos, Nigeria. Suggestions for future explorations are highlighted.

Keywords: 5I-flipped learning approach, mathematics, secondary school, meaningful learning, flipped classroom

1. Introduction

In most African nations, including Nigeria, research reports have shown a persistent and increasing underperformance of students in mathematics [1–3], and its rippling effects on other subjects (particularly science) have raised concerns. Efforts to address this concern have led to questioning the effectiveness of the approaches employed to teach mathematics at all levels of education [4,5] in enhancing students' learning outcomes. While the traditional teaching method has faced several criticisms and was empirically proven ineffective for enhancing mathematics achievement, there has been a plethora of research showcasing the positive impacts of various student-centered approaches, including the game-based approach [6,7], problem-based learning [8,9], and the flipped classroom [10,11] on students' mathematics achievement. However, the persistent in low performance suggests that lack of students' motivation to learning mathematics presents obstacles to achieving desirable and sustainable learning outcomes. Given its emphasis on abstract reasoning, problem-solving, and sequential learning, mathematics as a subject requires active engagement accompanied with unwavering interest in learning.

The flipped classroom model has shown potential for enhancing students' engagement in learning [12,13]. This approach, popularized by Bergmann and Sams [14], inverts the conventional sequence of teaching by delivering instructional content outside of class, typically through video lectures or online modules, while reserving in-class time for collaborative activities, problem-solving, and applied learning. Instructors employ this model to enhance students' engagement and motivation [15,16], improve students' cognitive load management and learning outcomes [17,18], and encourage students' independent learning [19,20].

Research has shown a generally positive impact of the flipped classroom on students' mathematics achievements compared to the conventional lecture method [17–20]. However, while there is growing interest in the use of the approach to enhance mathematics performance in African classrooms [10,21–23], findings indicate that its implementation faces significant contextual challenges, and there is very little research on how best to adapt the flipped classroom to the African context. Moreover, studies have found that the design of the flipped classroom is rarely grounded in theoretical frameworks [24,25].

For example, in a systematic review of 30 studies conducted by Wright and Park [24], the findings indicated that the very few studies in science and mathematics that reported explicit theoretical frameworks provide scant descriptions of what the in-class activities entail. It was noted that many of the studies implied active learning and group problem solving without sufficient detail to understand how the problems were completed. This has practical implications for the implementation of the flipped instruction, particularly in African classrooms where infrastructural and motivational barriers present notable challenges. The applicability of an intervention will likely be impossible without a theoretical framework guiding the design of the intervention [26]. Given this backdrop, this study aimed to address the challenge of applying and adapting the flipped classroom model for teaching mathematics in the African context with the design of the 5I flipped model, which is deeply rooted in social constructivist theory.

1.1. Flipped classroom models in Africa and their limitations

> …there is no single way to flip your classroom—there is no such thing as *the* flipped classroom. There is no specific methodology to be replicated, no checklist to follow that leads to guaranteed results. Flipping the classroom is more about a mindset:

> redirecting attention away from the teacher and putting attention on the learner and the learning. Every teacher who has chosen to flip does so differently. [14, p 11].

This background indicates the dynamism of flipping the classroom during teaching and learning exercises, depending on the learning context, but with the aim of enhancing students' engagement and learning outcomes. However, the literature suggests that the commonly adopted model of the flipped classroom is one that offers technology-based individual learning activities outside the classroom and interactive learning activities inside the classroom. For this model, the out-of-class activity consisted primarily of watching lecture videos at home, prior to the class, while in-class activities involved engaging students in interactive sessions.

The suitability of this model for effective teaching and learning in African classrooms raises concerns. Various studies within African context have highlighted unique obstacles and limitations faced by educators and students in adopting the flipped classroom model in secondary schools [1,10,11]. Prominent among these challenges is the assumption that all students have equal access to technology to carry out the pre-class activities. For example, it has been noted that students fail to complete pre-class tasks (such as watching videos) and become unprepared for face-to-face engagement in the in-class activities [10]. In Africa, many students at the secondary school level lack access to internet-enabled devices (personal computers or mobile devices), which are essential for accessing pre-recorded lectures and online learning materials at home [26]. According to a study conducted in Ghana by Aidoo et al. [1], only a small percentage of students have access to the necessary technology for participating in a flipped classroom, leading to significant disparities in learning opportunities. Similar findings were reported by Ekpoto et al. [28] in Nigeria, where limited access to technological resources hindered the effective implementation of flipped learning.

While flipped 2.0, a model of flipped classroom that allows students to watch videos or engage with other learning materials in the classroom rather than out of the classroom, would have been a suitable substitute, as demonstrated in some studies outside the context of Africa [29–31], however, the infrastructure constraints in African countries further exacerbate the situation. Many educational institutions in Africa struggle with inadequate power supply, limited internet bandwidth, and outdated technological infrastructure. In Nigeria, frequent power outages and unreliable internet connections are major barriers to the successful implementation of flipped classrooms [32]. These infrastructural limitations not only impede students' ability to access pre-class materials but also disrupt in-class activities that rely on technology.

Additionally, it is popular among African students to display a lack of interest or motivation to learn. Many of the students struggle with the self-regulatory skills needed for independent learning due to various socio-economic factors. For example, Olakanmi [33], in a study conducted in Nigeria, found that students from low-income backgrounds experience challenges in accessing and engaging with online materials due to a lack of resources and the necessary study environments at home. These groups of students, when not supported, demonstrated a lack of interest in completing the pre-class assignments and participated passively in in-class activities.

Furthermore, the effectiveness of the flipped classroom for teaching and learning in most African classrooms has been limited by the difficulty of managing classroom interactions during in-class activities. Chakawodza et al. [34] noted, in a study conducted among grade-12 students in South Africa, that the interactive nature of in-class activities may result in increased noise levels and off-task behavior if not managed effectively. In many African classrooms where there are larger classes, maintaining student engagement and ensuring productive collaboration can be particularly challenging. Teachers need to establish clear expectations and structures for in-class activities to minimize disruptions and keep students focused on the learning objectives. The use of structured group work that allows students to collaborate and share knowledge in groups, and setting clear task guidelines can help mitigate these issues and enhance classroom management in flipped learning environments [35,36]. Navigating this challenge has also seemed feasible with the adoption of a fully online model of the flipped classroom [37].

With the fully online flipped classroom model, students are expected to complete pre-class tasks (for example, watching videos and studying learning materials) through a learning management system or other interactive media tools and attend class discussions online through video conferencing platforms such as Zoom [38,39]. So, rather than the students interacting physically, which could result in increased noise level, virtual interaction affords the instructor the facility to control the noise level and allow students to interact in a coordinated environment. For instance, a study conducted by Hew et al. [38] showed that the Zoom video conferencing app allows instructors to create breakout rooms for students to interact in groups, while the "mute all" option and the virtual hand raising helped to maintain decorum during classroom interactions. However, we would remiss not to note that this model of flipped classroom has limitations, the majority of which are related to the technological challenges associated with the conventional flipped classroom, making its use for effective teaching and learning in African classrooms daunting.

While some studies have recommended design principles that could address each of these limitations of the conventional flipped classroom (mostly for courses in higher education), we are not aware of any research that provides a holistic instructional sequence that caters to such limitations and that is practicable and replicable for planning learning activities for secondary school students in the African context. Beyond this, there is limited availability of research that reports what aspects of the flipped classroom explicitly benefit mathematics teaching and learning within the African classroom context. This study presents the design of a robust model, the 5I model, for implementing the flipped classroom at secondary schools in African classroom settings while exploring its effectiveness for meaningful teaching and learning experience in mathematics.

The 5I model consists of five phases of learning activities: Immerse, Interact, Illustrate, Illuminate, and Incentivize (see Figure 1). This model rests on the theoretical frameworks of Vygotsky's theory of sociocultural learning and Ausubel's theory of advance organizers, providing a realistic instructional sequence for meaningful learning.

Immerse: In the first phase of the learning process, the teacher introduces the concepts to the students for the first time and engages them in the learning content by assigning pre-class tasks to be completed at home before in-class activities. The tasks include watching lesson-related YouTube videos and reading content-related texts from online sources. With the knowledge gained from the videos and web sources, students have to attempt some practice exercises that are also given by the teacher. While the students get immersed in the tasks, they note their observations and questions for further clarification during physical interactions in the classroom. This phase was designed to allow the students to acquire some prior knowledge that will accelerate comprehension and deepen the understanding of the incoming information in classroom learning.

Interact: The interaction phase of the learning process occurs in the classroom during face-to-face in-class activities. During this phase, the teacher introduces the topic again to help the students reflect on what they learnt at home. Then, the teacher divides the students into mixed-gender and mixed-ability groups to exchange ideas or knowledge acquired from the pre-class activities. The goal is to foster scaffolding among the students as they learn more when collaborating with their peers who have higher cognitive abilities [40]. The teacher also appoints a group leader for each group to coordinate the interactions.

Illustrate: After the group interaction, a volunteered member of each group presents a summary of all members' submissions to the entire class. The presentation, which is expected to last a few minutes, involves explaining or solving any of the pre-class exercises that accompanied the activities in the Immerse phase. During this phase, the teacher listens to the students' presentations and observes whether they have a complete grasp of the core concepts. The students are allowed to ask questions, and when none of their peers is able to provide an accurate answer, the teacher intervenes. This phase is designed to foster active participation of students in the learning process and to ensure that the learning takes place in a controlled, interactive environment.

Illuminate: As the teacher provides answers to the questions, they also shed light on any grey areas of the subject matter. The teacher also asks questions to identify any knowledge gaps, which may necessitate a detailed explanation of the concepts. This phase is usually led by the teacher, who provides more information to help students synthesize the new knowledge while clarifying some misunderstandings or misconceptions regarding the concepts.

Incentivize: The 5Is model uses formative assessment to evaluate the students' understanding of the concepts, and also to motivate and sustain their interests in the learning content. During this phase, the teacher may employ any form of incentive (except monetary reward) to encourage and sustain the interest of the students in the learning activities, considering what best suits the educational context. For the example of the incentive approach employed in this study, see the "5I model of flipped classroom" section under the methodology section. Every lesson closes with a brief summary of what was learned in the class; the teacher informs the students about the next lesson and instructs students to meet with their group leaders to obtain the lesson videos.

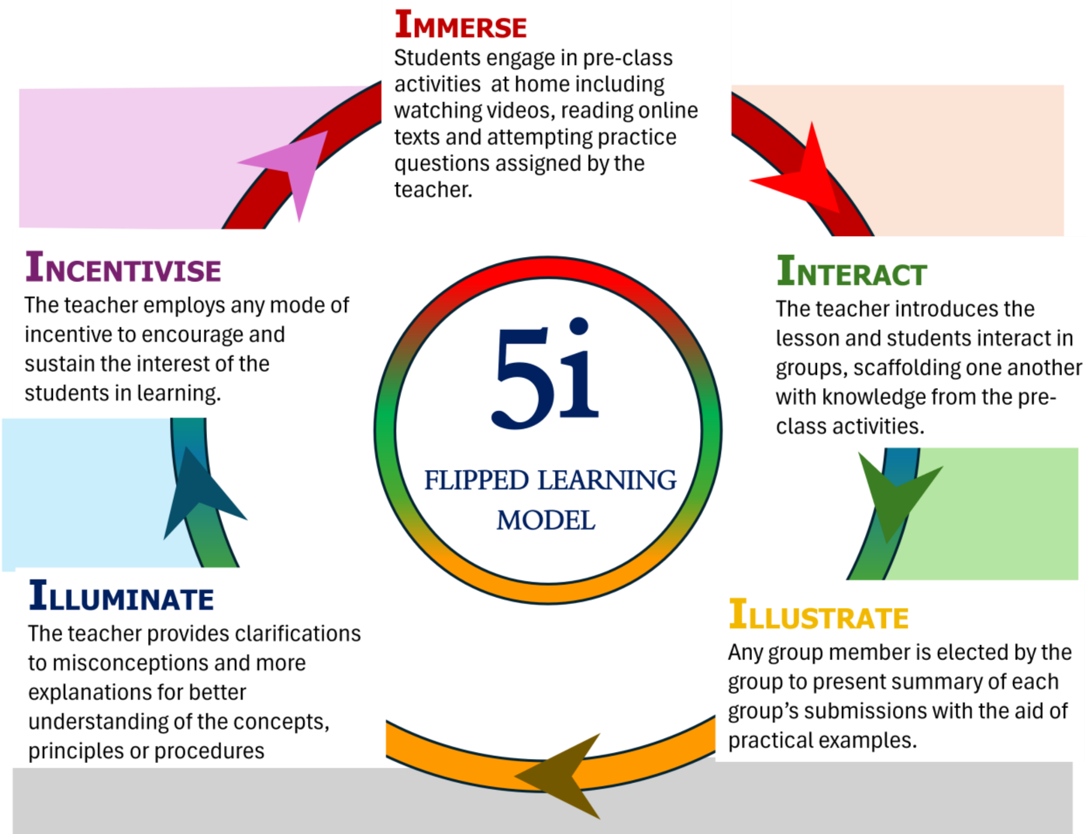

Figure 1. The 5I model at a glance.

1.2. Objectives of the study

To test the effectiveness of the 5Is model on learning engagement and outcomes, this study investigated its impact on secondary school students' mathematics achievement by comparing it with a conventional flipped classroom. For an explicit account of any features that contribute significantly to students' learning and how such contributions occurred, we sought students' and teachers' perceptions on how the flipped models (5Is and the conventional flipped classroom) contributed to teaching and learning. Specifically, the following research questions guided this study:

1. What is the impact of the flipped classroom models on secondary school students' achievement in mathematics?
2. What are the students' and teachers' perceptions of the value of the flipped classroom models for mathematics teaching and learning?

2. Theoretical frameworks

The theoretical underpinnings of the 5I flipped classrooms model are deeply rooted in the educational theory of social constructivism [40] and Ausubel's theory of advance organizers [41]. The fundamental underpinning of Vygotsky's sociocultural theory is that learning emanates from social interaction with students, parents, peers, teachers, and society. Students actively construct their knowledge and make meaning of concepts as they interact with more knowledgeable others, who guide them to learn better [27]. It deals with the concept of scaffolding and zone of proximal development, theorizing that students understand better when they collaborate with others (peers, teachers, or parents) who are more advanced in knowledge or have a wider range of skills than the students currently do. These more knowledgeable others are referred to as the "scaffolding" who help the students expand their knowledge and skills beyond what they can learn or do independently. This level of knowledge is what Vygotsky refers to as the zone of proximal development (ZPD). ZPD is the set of skills or knowledge a student is not able to acquire independently, but can do with the help of the scaffolding (teachers or peers). Hence, the social constructivist theory asserts that students learn most when they are in their ZPD. This educational approach can support learning by increasing students' engagement.

How does this theory fit smugly with the 5I model? The 5I flipped learning model hinges on the premise that meaningful learning is attained through socially interactive learning techniques. The immerse phase of the 5I model allows students to interact with meaningful learning materials through social media to obtain prior knowledge on a given topic before classroom activities. By watching videos and attempting accompanying tasks, the pre-class activity presents opportunities for students to think about, reflect on, and apply ideas. This repeated interaction with learning material deepens learning [25]. The theory of ZPD and scaffolding proposes that lessons should begin with an introductory discussion or questioning about what students already know regarding the given topic. This will allow the teacher to assess students' current level of knowledge, which enables the teacher to provide effective scaffolding support and help the students to learn meaningfully in their ZPD. The pre-class activities of the 5I model clearly align with this theory. In the pre-class (Immerse phase), students obtain baseline knowledge on the given topics by watching lesson videos and trying to solve practice questions; they advance their learning zone to their ZPD through scaffolding-related activities during in-class learning. Since each student can have a different ZPD, the in-class activities in the 5I model ensure that every student's ZPD is catered for through a series of scaffolding activities, such as group discussions during the interaction phase, group presentations (Illustration phase), and problem-solving (Illuminate phase). More importantly, these interactive activities create the social setting that the constructivist learning theory encourages.

In Ausubel's theory of meaningful learning [41], an advance organizer refers to a tool used to introduce learning content to students that helps them connect the new incoming information with their prior knowledge. An advance organizer is designed to activate students' prior knowledge by giving a general overview of the given topic, highlighting key concepts, and reminding the students about relevant prior knowledge, which provides a framework for understanding the new information. Ausubel proposed the theory of advanced organizers to help students learn meaningfully by relating new concepts to what they already know. Hence, by using advanced organizers, teachers can improve students' engagement, comprehension, and retention of new information. This learning model supports the design of the pre-class activities of the 5I flipped model.

The pre-class introduction of concepts, lesson videos, and the accompanying pre-class tasks are advanced organizers, which enable students to acquire some foundational knowledge about the content. When this knowledge is reinforced during in-class activities, students are able to obtain meaningful learning of the contents by connecting the classroom information to the knowledge acquired at home. The advanced organizers are designed to provide mental scaffolding for the students, making it easier for them to incorporate into their cognitive schemata the new (complex or other difficult) information or material [42,43].

3. Methods

3.1. Participants

This study was conducted in Lagos state, Nigeria, using samples from public senior secondary schools in the education district IV. Two schools were purposefully selected based on accessibility to internet-enabled devices, which is the major condition of learning in this study, particularly after school hours. The two schools correspond to the two learning conditions: the conventional flipped classroom and the 5I model flipped classroom assigned to the control and experimental groups, respectively (see Table 1 for the distribution of the study sample). While mathematics was a general subject for all students regardless of department and class year, senior secondary two (grade level 11) students were selected as the participants for this study.

This class of students was considered appropriate for this study, given that they had spent a full academic year in the senior class one, in addition to their junior school mathematical learning experience. As such, it was assumed that they would have developed the five categories of skills needed for learning mathematics and for participating in this study. These include physical skills (enabling the use of tools), social skills (ability to work in groups), attitude development (persistence in problem solving and follow-up skills), conceptual development (able to make inductive-deductive reasoning and process skill development), and practical skills. Students' proficiency in these skills was considered vital to ensure active partipation in the learning exercises (such as guided inquiry: online and offline, collaboration and group discussion, and presentations) to which they were exposed during treatment. To avoid any participant interactions that could result in confounding bias, it was ensured that the participating schools were geographically distanced from one another.

Two mathematics teachers participated in this study. The teachers had a bachelor's degree with a minimum of ten years of experience in teaching mathematics at Lagos state secondary schools. Baye (pseudonym), who taught the experimental group, had 10 years of teaching experience; Nayn (pseudonym), who taught the control group, has been teaching mathematics for 12 years. Although three teachers were identified as mathematics teachers in each participating school, we selected these teachers based on the equivalence in their professional characteristics. We recognize this as an important consideration in controlling for teachers' effects that could undermine the validity of comparing the two teaching conditions.

Table 1. Study sample.

Design	Learning conditions	Participants
Quantitative	Conventional flipped classroom (control)	N = 106 (male = 47; female = 59)
	5I model of flipped classroom (experimental)	N = 102 (male = 54; female = 48)
Qualitative	5I model of flipped classroom (experimental)	N = 20 (high performing students = 10; low performing students = 10)
	Conventional flipped classroom (control)	Teacher = 1
	5I model of flipped classroom (experimental)	Teacher = 1

3.2. Design and procedure

To address the objectives of this study, a mixed method (explanatory sequential) design involving quantitative and qualitative approaches was adopted to provide a deeper understanding of the research problem than would have been achieved by either quantitative or qualitative method alone [43]. The quantitative approach was quasi-experimental since data were collected from the students in intact mathematics classes. The qualitative approach allows the collection of data through in-depth individual interviews of selected students in the experimental group, as well as the teachers of both the control and experimental groups. Students selection for the qualitative phase was based on consistent active participation in class and performance in the test. Thus, in order to obtain a wider range of understanding, 20 groups of students whose levels of participation and performance were positioned at opposing ends of the spectrum were selected for the interview (that is, 10 high-performing and 10 low-performing students).

Data collection procedure, which included the administration of the pretest, the treatment phase, the administration of the post-test, and the students' and teachers' interviews; all spanned across five weeks, which corresponded to the regular periods for learning algebraic expressions, which is the topic of interest in this study. This was arranged to avoid any disruptions to the planned study scheme for the two classes over the term. However, the retention test (delayed post-test) took place four weeks after the completion of the lessons to measure the knowledge retained by the students.

The instruments used in gathering the data for this study include a mathematics achievement test, the students' perception interview guide, and the teachers' perception interview guide. The mathematics achievement test was designed to collect quantitative data on students' performance. This instrument was developed by the authors in collaboration with two experienced mathematics teachers. The items in the instrument were designed with reference to the structure of West African Senior School Certificate Examination questions and an adaptation of questions from two commonly used senior secondary school mathematics textbooks. Following the 20 golden rules for setting multiple-choice questions [45], the items included 30 discrete multiple-choice questions with four options, with three distractors and one key for each item. The items were designed to measure five levels (understand, analyze, apply, evaluate, and remember) out of the six levels of cognitive learning dimension, according to the revised Bloom's Taxonomy [46]. This is to ensure that the test captures all the highlighted learning objectives.

The instrument was subjected to validity and reliability testing. The validity of the instrument was carried out by a panel of five experienced mathematics teachers who were consulted to assess the essentiality of each test item. Using Lawshe's method [47], the content validity ratio (CVR) of each item was calculated, and six items were found to have low CVR. These items were reviewed and revised based on the experts' feedback. The instrument was then administered to 97 senior secondary two (11th grade) students outside of the study sample to check and revise the ambiguity of the questions and to further validate the fitness of each item. With the assistance of the school mathematics teachers, the questions were read aloud to the students, who were given the opportunity to voluntarily explain what they understood or what they were expected to do on each question. The result of this exercise led to the restructuring of 3 test items, which, based on the students' interpretation, were considered ambiguous and not appropriate for testing students' cognitive knowledge and understanding of the topics.

Furthermore, a pilot test of this instrument was conducted to validate the accuracy of the allotted time duration for the test. Using senior secondary three (12th grade) students from a school of choice (but not the participating schools), the test was administered to 68 students. Since this class of students had been taught the topic, it was assumed that they had conceptual understanding and thus were appropriate for determining the accuracy of the allotted time for attempting the test. Over half of the students completed the questions under the allotted time (40 minutes), indicating that it was accurate for the test.

To determine the internal consistency of the instrument, a split-half reliability measure was used. The test was administered to non-participant senior secondary two students in a different school, after which the items were split into even and odd-numbered items and scored accordingly. The scores were further subjected to the Split-Half Reliability test; a Spearman brown coefficient of 0.83 was found, indicating that the instrument consistently gave similar results at least 8 times out of every 10 times it was used.

The students' perception interview guide was designed to assess the perception of selected students from the experimental group about the impact of the instructional delivery. This instrument contained eight semi-structured questions, posed in a way that the students were easily able to understand what was being asked, allowing them the opportunity to elaborate on each response. The interview guide begins by asking the students to describe their learning experience during the lessons; it then narrows down to specific and follow-up/probing questions about how each aspect of the teaching approach contributed to their meaningful understanding of the concepts (e.g., students were asked "Were there any activities in particular that aided your understanding of the concept during the lessons?" and "In what ways did this activity help you learn better?"). This approach enables a natural flow of conversation between the interviewer and interviewee, which supports obtaining correct and maximum information [48–50].

The first draft of this instrument was sent to three independent experts in qualitative research to assess the clarity and relevance of the questions to the objective of the study. The experts provided comments and suggestions that addressed ambiguity and sequence. Based on this feedback, the instrument was revised to enhance the understanding and sequence of the questions. After the revision was made, the instrument was sent back to the experts for a second-level assessment, and the instrument was adjudged valid for its intended purpose.

The students' interview took place at a quiet location within the school premises, as authorized by the school principals. Before the interview, students were reminded that the session was being recorded and that conversations were confidential and strictly for academic and research purposes. The setting for the interview was prepared in such a way that the interviewer and the interviewee were seated facing one another with a table in the middle, with two glass cups of water and a recorder placed on it. This setting helped to ensure that the interviewees felt relaxed, confident, and comfortable [44]. The interviews took place between 9:00 am and 11:00 am (before the long-break hour) to ensure that students were not exhausted and/or distracted due to long-break activities. The interviewees' responses were recorded, while some salient points (especially those expressed through nonverbal cues) were noted. Each interview session lasted about 6 to 8 minutes. The interview of the experimental group teacher was conducted in the same setting after the students' interviews, while that of the control group teacher took place in the control school.

The flipped learning conditions consisted of teaching the students the selected subtopics from the algebraic expression based on the designed learning objectives for the term. The subtopics consisted of the simplification of algebraic expressions, operations on algebraic expressions, and factorization of algebraic terms, including quadratic equations, algebraic fractions, and algebraic identities.

3.3. Design of the flipped learning conditions

In this section, we describe the learning activities that took place in each of the flipped mathematics classrooms: the conventional flipped classroom (control) and the 5I model of flipped classroom (experimental). Prior to the teaching exercise, the two participating teachers were offered training on the implementation of the flipped approach. This training includes the provision of teaching materials, lectures, and micro-teaching sessions to deepen the teachers' understanding of the design and details of each flipped learning condition. The training took place simultaneously at different locations to avoid interactions between the teachers, which could confound the impact of the interventions. After the training and certification of the teachers as effectively being able to implement the flipped approaches, the authors worked with the teachers to prepare a standardized lesson plan for both groups based on the learning objectives of the topic. The lesson plan was examined by each participating school head and declared appropriate for the lessons.

An effective implementation of the flipped classroom requires well-planned lesson videos, notes or slides, and teaching materials prepared ahead of the lessons. Hence, with the collaboration of the authors and the teachers, related lesson contents were searched on YouTube; from the results obtained, links were edited and renamed to capture the subtopics of interest. The videos were saved to a memory card designated for the lessons. These videos were used in both control and experimental groups. Authors, however, argue that it is difficult to find videos on YouTube or other online video platforms, like Khan Academy, that effectively cover the learning objectives of mathematics topics taught in school. Given that we are in the social media world, where students immerse themselves in YouTube, Facebook, WhatsApp, Instagram, and other media platforms for mostly frivolous activities, it is in the interest of this study to steer students' engagement with these platforms into meaningful learning activities.

3.3.1. The conventional flipped classroom

As there is no standardized design for implementing the flipped classroom model, the implementation of the conventional flipped classroom in the context of this study involves engaging the students with the mathematics content through watching videos at home and then using in-class time for interactive learning activities. Each lesson began with a pre-lesson assignment asking the students to watch content-related videos from YouTube before coming to class. The in-class activities, which varied from lesson to lesson, usually began with question-and-answer sessions, where the students, who came to class with self-generated questions from the videos, asked questions to improve their understanding or clarify misconceptions; the teacher helped to clarify the concepts.

Classroom activities involved students solving practice questions given by the teacher, while the teacher moved around the class attending to individual students' needs. During the first lesson, it was at this stage that the teacher realized that many of the students had not watched the lesson videos, as they were struggling with the practice questions. As lessons progressed, week by week, there were improvements in the number of students who came prepared for the class activities. Still, the teacher faced difficulties in monitoring the progress of a large proportion of the students, as they could not follow up with the lesson progression due to their failure to watch the lesson videos. To help such students, the teacher allowed them to interact with one another while attempting to solve the practice problems. At the end of the practice session, the teacher provided support to the students who seemed not to understand the concepts, so they could use the feedback to improve their understanding.

3.3.2. The 5I model of a flipped classroom

Similar to the conventional flipped classroom, the 5I model learning contents had 5 subtopics treated over a five-week period. Each subtopic was treated in two sessions per week (80 minutes per session). The teaching and learning of algebraic expressions in this classroom were designed using the 5I framework, which consists of five phases of learning progression. Like the conventional flipped classroom, every lesson has pre-class and in-class activities.

For example, in the pre-class phase of lesson 1 (simplification of algebraic expressions to their lowest terms), the teacher introduced the concept and provided three YouTube video links for students to get acquainted with the principles or steps for simplifying algebraic fractions to their lowest terms. The teacher also provided a list of ten practice exercises that all the students were instructed to attempt. The exercises consisted of basic and advanced questions, knowing that the videos were robust enough to cater for the two knowledge levels. This helps to eliminate the regular syndrome of mathematics lessons where the questions used as examples in the class are always easy, while complex questions are given as homework or in tests and exams. See Figure 2 for a screenshot of some practice exercises. These tasks got the students **immersed** in the lesson contents as they noted down their observations and questions for further clarification in the classroom.

It is important to note that prior to the beginning of the lessons, the teacher met with the students and asked them to submit their WhatsApp contacts (those without mobile devices were asked to submit their parents' contact), and a WhatsApp group had been created. During the first lesson, the teacher provided links to YouTube videos through the WhatsApp group. This helped to reduce the excessive data required if students were asked to search for the relevant videos themselves. In the subsequent lessons, since the students worked in group, the teacher shared the downloaded videos with the group leaders, and each group leader was required to share the videos with the group members through the agreed platform within each group, ensuring that at least half of the group members had offline access to the videos. Alternatively, the students were encouraged to visit their friends who had access to either online or offline videos. Given these multiple routes of accessing the lesson videos, the 5I model has been able to address, to a significant extent, the challenge of students not watching the videos due to limited access to internet services.

Simplify the algebraic fractions

1. $\frac{x^2+5x+6}{x+2}$
2. $\frac{5x^2-10x}{x(x-2)}$
3. $\frac{x^2-5x+16}{x^2-7x+12}$
4. $\frac{4x^2-9}{2x^2-5x+3}$
5. $\frac{x+7}{x^2-x-6} - \frac{3}{x-3} + \frac{2}{2x+4}$

Operations on algebraic fractions

1. $\frac{x}{x+2} + \frac{2}{x-2}$
2. $\frac{2}{x} + \frac{3}{x+1}$
3. $\frac{7x}{x^2-4} - \frac{3}{x+2}$
4. $\frac{\frac{6x}{x^2-4}}{\frac{2}{x-2}}$
5. $\frac{1}{x+3} + \frac{2}{x-3} = 0$, solve for x

Factorization of algebraic expressions

1. $x^3 - 3x^2 + 2x - 6$
2. $2a^2b - 3ab + 5ab - ab^2$
3. $x^2 + 11x + 24$
4. $3a^2b - 6ab^2$
5. $4x^2 - 16y^2$
6. $9x^2 - 25$

Figure 2. A screenshot of practice question examples.

During the in-class session of the first lesson, the teacher re-introduced the concept and divided the students into 10 groups (a maximum of 12 students in a group) to facilitate peer **interactions** or group discussions on how to simplify algebraic fractions to their lowest term within 8 minutes. The teacher was aware of the intellectual capacity of most of the students; thus, while grouping the students, emphasis was placed on the condition of mixed ability in a group. This was done to promote instructional scaffolding for the weak students who were still unable to grasp the core ideas of simplifying algebraic fractions after watching the videos. The teacher also asked if there were students who did not watch the lesson videos. A few students identified themselves, and the teacher ensured that these students were grouped among those who watched the videos, so they could learn from their peers. So, while not watching the videos remains a challenge for effective implementation of the flipped classroom, the 5I model caters for the resulting lag in students' participation through scaffolding. It is worth noting that the grouping process was only featured in the first lesson; in the subsequent lessons, the students automatically went to their assigned groups after the teacher reintroduced the lesson.

The group discussion further aided understanding; during presentations, students were able to use some of the practice questions to **illustrate** their understanding of the concept. During the presentations, the teacher interjected to **illuminate** the principles of simplifying algebraic fractions when they observed that some students divided algebraic fractions through the addition and subtraction signs, which indicated a misconception of the dividing rule. For example, a student simplified the expression $\frac{x-4+3}{x+1}$ by simply crossing out the 'x' in the nominator and the denominator. The teacher explained how this problem should be solved and used other related questions to explore the division rule of algebraic fractions.

To evaluate students' understanding, the teacher wrote a list of 10 practice questions and asked anyone from a group to solve one question each. A maximum score of 10 was set for each question, and this was awarded to each group that completed the task. After the completion of the tasks, the teacher announced and applauded the group with the highest score. The scores accumulated weekly; at the end of every week, the teacher took pictures with the winning group, and some printed copies of the photographs were posted on the school notice board, captioned "the best mathematics group of the week". These were the **incentives** employed to engage and sustain the interest of students in every lesson for the five weeks.

4. Data analysis and results

Research question 1: What is the impact of the flipped classroom models on secondary school students' achievements in mathematics?

To address the first research question, the post-test (retention) scores of students in the conventional flipped classroom and in the 5I model of flipped classroom were compared. Given that students were not randomly selected to participate in this study, analysis of covariance (ANCOVA) was considered appropriate for the comparison using the pretest and the retention test scores. The scores were first subjected to normality and homogeneity of variance tests to check if the sample was drawn from a normal population and if there were significant differences in the students' prior knowledge of the concept. The results showed that the scores for both the conventional flipped [$W(102) = 0.97$, $p > 0.05$] and the 5I model of flipped classes [$W(106) = 0.98$; $p > 0.05$] were normally distributed, as assessed by the Shapiro–Wilk's test. Levene's test also indicated that the groups had equal variances in their performance ($F = 1.86$; $p > 0.05$).

Having met these assumptions for the use of a parametric test, an analysis of covariance (ANCOVA) was conducted to determine if there were differences in the scores (retention test score) of the two groups. Descriptive statistics showed that students in the 5I flipped classroom model (M = 19.63; SD = 3.17) had a higher mean score than the students in the conventional flipped classroom (M = 15.99; SD = 4.17), with a mean difference of 3.64 between the groups. The ANCOVA summary table (Table 2) indicated that the difference in the mean scores of the two groups was statistically significant [$F(1,205) = 82.87$; $p = 0.00$].

Table 2. ANCOVA statistics for differences in the mean scores of experimental and control groups.

Source	Type III sum of squares	Df	Mean square	F	Sig.	Partial eta squared
Corrected model	1130.26[a]	2	565.13	48.43	0.00	0.32
Intercept	2559.60	1	2559.60	219.35	0.00	0.52
Pretest	442.72	1	442.72	37.94	0.00	0.16
Group	966.94	1	966.94	82.87	0.00	0.29
Error	2392.12	205	11.67			
Total	69233.00	208				
Corrected Total	3522.38	207				

Research question 2: What are the students' and teachers' perceptions of the value of the flipped classroom model for mathematics teaching and learning?

In addition to the quantitative data, students' and teachers' interviews were conducted to obtain a deeper understanding of the impact of the flipped models. Audio recordings of the participants were listened to and transcribed independently by three researchers. The transcripts were then read and coded inductively using relevant keywords, phrases, and sentences identified from the responses. The codes were reviewed by the authors independently by reading through the transcribed data to get a broad sense of what the codes revealed, ensuring that there were no inconsistencies and that no relevant words had been overlooked. The code description was then revised as necessary.

The students' codes were categorized into themes, while teachers' responses served as the classroom observation data describing the conditions of the learning environment, how the students participated in the classroom, the challenges encountered in implementing the model, and suggestions for effective and efficient implementation of the model to achieve meaningful learning outcomes. Beyond presenting the findings in the result section (in narrative form with direct quotes), the responses are also used to corroborate or contradict the arguments in the discussion section. For easy reference, the following represent the names of the flipped classroom teachers.

Nayn (pseudonym): conventional flipped classroom teacher.

Baye (pseudonym): 5I model flipped classroom teacher.

To ensure the credibility of the data, a member check was performed on the interview data. Due to the difficulty in reaching out to the students again after the completion of the study, the member check of the students' responses was done by giving a written report of the findings and recorded audios to three colleague researchers to confirm if the interpretations accurately aligned with the students' responses. On the other hand, the two teachers were contacted and informed about the purpose of member checking, and they consented to participate. The prepared transcripts, along with the recorded audios of their interview sessions, were provided to the teachers, who were asked to review the data and provide feedback on its accuracy.

4.1. Students' perception: The value of the 5I flipped model for learning mathematics

4.1.1. Student-centered approach

The students perceived that the learning activities in the 5I model were student-oriented and helpful to achieving a meaningful understanding of mathematics concepts. This was noted in their responses when they expressed satisfaction about being the focus of attention throughout the learning process. A response from Kunle (pseudonym) reads:

> What I love most is the fact that, in all the lessons that we had, the teacher focuses his attention on us. He was always ready to answer any question that we asked. Even when we were watching the videos at home and maybe something was not clear and we asked him questions on the WhatsApp group, he tries to explain to us.

4.1.2. Enhancing critical thinking

Learning mathematics with the 5I model of flipped classroom was found to be an approach that enhances students' critical thinking skills. The students whose responses resonate with this idea emphasize the value of the approach as contributing to developing their ability to think critically while solving complex mathematical problems. They explained that the logical connection of ideas from the contents viewed at home and those discussed in the classroom instigated critical thinking when solving tasks given in class. For some of the students, it made it easier to solve more complex algebraic expressions through the application of knowledge. Bukunmi (pseudonym), a female student, said:

> Before now, I studied mathematics by cramming solved examples and exercises we did in class to prepare for tests and exams. And usually, I ended up not doing well in the exams because the questions are always more complex than the exercises and examples treated in class. But these five weeks of lessons have taught me that every mathematics problem has its own unique solution and that I have to think very well before attempting any question.

4.1.3. Fostering knowledge retention

The students considered that learning mathematics within the context of this model fostered a deeper understanding of the concepts and allowed for knowledge retention. The students expressed this idea by explaining that the group work and presentation activities in the classroom sessions allowed them to engage in peer teaching and learning, which helps to concretize their knowledge of the mathematics concepts and retain the knowledge for future applications. Some of them relate this to the opportunities to learn from various sources, including videos, their peers, teachers, and also the contextual examples used to exemplify the concepts. For example, Dammy explained how she was able to remember what she had learned four weeks ago:

> …when I watched the videos at home, and I didn't quite understand some concepts, I did not worry so much because I knew that when I get to class, I can learn from different persons in my group and even from the presentations of other groups and also from the teacher. This made it easier for me to remember what was learned and helped me do well in the test.

4.1.4. Promoting deep inquiry and learning engagement

All the students interviewed expressed at least one statement indicating the value of the 5I model in promoting deep inquiry. The mantle of this responsibility was shouldered by the illustration aspect of the model. The students noted that the events of presenting their conceptual and procedural understanding of mathematical problems require them to clearly articulate their thought processes, leading to deeper inquiry into why certain steps or methods of solving a particular problem may not be appropriate.

Enthusiastically, the students reported that the sequence of activities they engaged with during their five weeks of learning algebraic expressions promotes their learning engagement cognitively, behaviorally, and emotionally. This was expressed with expressions like "I became more interested", "more concentrated", "I enjoyed the lessons", "you can do it yourself", and "more active".

Deborah: When you watch videos just to learn, it's easy to get bored and lose concentration, but when you know you will be presenting what you've learned to the whole class and with scores assigned to your presentation, you become more concentrated. That's my experience.

Adam: for the first lesson, I didn't even consider watching the videos for two reasons: first, there was not enough data to watch, and second, I did not consider it as anything serious. But then I read the instructions that came with the video links, the practice questions that we must solve, that we will present what we learn in class, and that we will be scored for our presentation, and the joyful one that says, "you will be provided some token as your data support". I quickly rushed to my mum to give me money to buy data and watched the video.

Emma: When we worked in groups, I found myself more active, asking and answering questions from my group members. This made me really enjoy the lessons.

Abibat: The take-home tasks that were given along with video links, I found them more motivating rather than challenging, because they help you to apply what you have learnt, and this helps you to know how to solve the tasks by yourself.

4.2. Teachers' perception: experience in flipped classroom models

4.2.1. Perception about the learning environment

When the teachers were asked to describe their perception of the learning conditions, their narrations indicate that, unlike the commonly used lecture method, the teachers perceived the flipped classrooms as interactive learning instructions that promote active participation of the students in the learning process. The teachers reported that before the intervention, they had always taught mathematics to their students using the traditional lecture method. This method often requires them to stand or sit at a desk in front of the class using the chalkboard (which later became a white marker board) to give notes and solve some textbook examples and practice questions for the students. They noted that they do not usually draw on technology or use any concrete materials or real-life experiences to enhance students' understanding in their mathematics classes. Their role was only to give notes and provide explanations on how to solve the mathematics problem being treated, while the students were expected to passively listen to the explanations as the classroom environment was devoid of any form of interactive activities, group work, or active learning. Nayn explained the change in the mathematics classroom condition as follows:

> In my regular math classes, I mean before the intervention, I often struggle with limited time constraints, and so I just give notes and solve a few simple examples in class while I give the students many complex questions as homework assuming that they will learn how to do them on their own or with the help of their seniors or siblings. This made it impossible to engage the students in active learning. But in the flipped classroom, since the students received lectures outside the classroom through the videos (although the majority of the students don't watch the videos), the available time for teaching was devoted to interactive sessions. While the students actively participate, I am able to evaluate their understanding as they learn. This completely changed the classroom environment from teacher-centered to student-centered environment.

Baye explained the change in his classroom environment by saying:

> I see the flipped classroom as an interactive learning condition that promotes active learning and interactions among the students and between the students and us, the teachers. The students were actively engaged with learning in the classroom as well as outside the classroom when they had to watch the videos and report their findings in class. And particularly, when they know that scores are assigned to their presentations. This kind of incentive motivated the students to prepare for the class by watching the videos. So, they came to class prepared and this made the class engaging and interesting.

4.2.2. Challenges in implementing the flipped classrooms

While both teachers perceive the flipped classrooms as interactive and engaging, they identified challenges in the implementation of the flipped classrooms. Nayn expressed a challenge in monitoring the students' learning activities in the class. He reported that since the classroom was always crowded, as mathematics is a general subject, the interactions between the students often result in a noisy learning atmosphere, which is usually difficult to control. He further reported that since many of the students were unprepared for the class (by not watching the videos due to a lack of data or unwillingness to watch), it became difficult to involve those students in class activities, as they often appeared lost and not carried along. On the one hand, Baye's responses, when asked about the challenges encountered during the implementation of the 5I model, indicated that the identified challenges in the conventional flipped classroom had been addressed using the 5I model. However, Baye noted the difficulty in managing the time and classroom activities during the first lesson, but the difficulty eased off in subsequent lessons. A direct quote from Baye reads:

> …. let me note that the workload on me on the first day of the lesson was quite overwhelming, I had the challenge of managing the time and all that…this is probably because the first lesson involves time-taking activities like the groupings, yes! the grouping. But in subsequent lessons, the story changed, you know… students already know the routine of the class activities, so they got into groups on their own and the lesson progresses with not much stress.

Baye added that he was able to observe the students' learning activities closely and provided them with immediate feedback, which helped to scaffold their learning. By grouping students with mixed abilities, he reported that he was able to manage the classroom activities as well as ensure that the weak students and those who did not watch the videos were not at a disadvantage in the classroom activities.

4.2.3. Suggestions for navigating the challenges of the flipped classrooms

When the teachers were asked to suggest ways to navigate the challenges they encountered with implementing each of the flipped classroom models, Baye suggested that, for effective classroom interaction, particularly on the first lesson, the teacher should make sure to take a proactive stance by meeting with the students and grouping them in advance. This would have cut down the time taken to share the students into groups during the first lesson. He further noted that this advanced grouping will benefit the students in terms of accessing the videos and completing the pre-class tasks within the group. Baye also thinks making the parents aware of the demands of the learning instruction will facilitate the completion of the pre-class assignments, as parents could allow the use of their mobile devices or internet services for the completion of the pre-class activities. On the other hand, Nayn suggestions were already encapsulated in the 5I model, as he noted that a pre-planned structure of the classroom activities is required for effective implementation of the in-class sessions. He also noted that the students need to be motivated to watch the videos before coming to the class by using any form of incentive that is applicable and appropriate within the context of learning.

5. Discussion

While there is a plethora of studies on challenges of the conventional flipped classroom for meaningful learning among secondary school students in Africa, limited studies exist on possible advancement through the design of a structured model that addresses such challenges. This study investigated the impact of the 5I model flipped classroom on mathematics achievements of senior secondary school students, seeking teachers' and students' perceptions about the values, including the effective contribution of the model to meaningful learning.

As indicated in the results section, we compared the mean scores of students in the conventional flipped classroom and the 5I model flipped classroom, and a mean difference of 3.64 was found between the two groups, with students in the 5I model classroom having a higher mean score than that of the students in the conventional flipped classroom. This difference attained statistical significance, as shown by the p-value ($p = 0.00$) in the ANCOVA summary table (see Table 2). This result indicated that students in the 5I flipped classroom model performed significantly better than students in the conventional flipped classroom. The partial eta squared, which describes how much of the variance in the measured variable is explained by the independent variable, indicated that about 30% (moderate effect) of the change (improvement) in the students' mean scores can be attributed to the teaching strategies employed, suggesting the effectiveness of the 5I model relative to the conventional flipped classroom.

On account of the fact that test scores are limited in explaining the effect of interventions, we sought students' and teachers' perceptions on the value of the flipped classrooms to deepen our understanding of the impact of the intervention on the learning outcomes and to guide the interpretation and conclusions drawn from the findings. Using thematic analysis, the coding of the students' responses generated five themes, expressing the 5I flipped approach as a model that is highly student-oriented, enhances critical thinking, fosters knowledge retention, and promotes classroom engagement and deep inquiry. On the other hand, using a narrative approach, the teachers' experiences provided insights into how the learning conditions interplay with the students' cognitive and behavioral engagement with the mathematics content. Hence, we speculated that the possible explanation for the significant difference in the students' achievement lies in the values of the flipped classrooms as reported by the students in the experimental group and the teachers of the two groups.

Unlike the conventional flipped classroom, the 5I model offers a series of learning activities (in an organized structure) that are effective in enhancing students' achievement and other learning outcomes. These learning activities were also designed to address some of the challenges limiting the effectiveness of the conventional flipped classroom. For example, the interaction and illustration phases of the 5I model, which allow the students to discuss in groups and present their conceptual and procedural understanding of the mathematics concepts in the classroom, encourage the students to deeply engage with the learning materials in order to have a comprehensive understanding of the mathematical concepts. As noted by the students, these activities not only enhance the students' understanding of mathematics concepts but also promote their active engagement, deep inquiry, and critical thinking skills required for solving mathematical problems.

Through reflective thinking, critical evaluation, and feedback, the presentation of ideas enables the students to articulate their thought processes, reflect on their understanding and approach to solving mathematical problems, while exploring "how" some mathematical principles differ from others and "why" certain principles are most suitable for solving certain mathematical problems, thereby enhancing their critical thinking and inquiry skills. This finding aligns with the study by Erdogan [51], which emphasized the importance of peer interactions with reflective thinking in enhancing students' critical thinking skills. This finding is also closely aligned with the principles of social constructivism, where knowledge is constructed through interaction with peers or more knowledgeable others. When students discuss in groups and present the summary of their discussions, they engage in a meaningful dialogue with their peers and instructors, and through questioning and feedback (scaffolding), they are able to construct and refine their knowledge and achieve higher levels of understanding of the concepts—a level called the zone of proximal development (ZPD) [40].

Besides learning from one another, students also learned from the teacher when he illuminated the mathematics concepts by clarifying students' misconceptions, further providing a more detailed explanation using contextually relevant examples. This opportunity to learn from multiple sources logically explains the better performance of the students in the 5I flipped classroom. As enunciated by Oladejo et al. [52], the acquisition of knowledge from multiple sources provides unique opportunities to understand new complex concepts and allows for the retention of knowledge for longer periods. This assertion was also corroborated by the students' reports (for example, see excerpts from Dammy in the results section).

In agreement with the students' perceptions, the teachers (Baye and Nayn) perceived their classroom environment to be student-centered, interactive, and engaging. However, Nayn (the teacher of the conventional flipped classroom) expressed challenges in closely monitoring the students' learning activities and engaging every student in the classroom activities. The reasons for this (as noted by Nayn) were the fact that the classroom was always crowded, with a chaotic, noisy environment during interactive activities, and the majority of the students often missed the learning progress by failing to watch the lesson videos. Consistent with the findings of previous studies on the use of flipped classrooms, these concerns emphasize some limitations already identified in effectively implementing the conventional flipped classrooms in Africa [1].

In the 5I model of the flipped classroom, the teacher managed to create a peaceful, interactive, and engaging teaching and learning environment, where the students collaborated and actively participated in mathematical activities. This was achieved through multiple ways; first, unlike the conventional flipped classroom, every minute of the classroom interaction was pre-designed for different activities that progressed from one phase to another. This afforded the teacher the opportunity to monitor and control students' interactive activities. This claim is supported by several studies on interactive classroom management [53–55]. For example, Nagro et al. [54] found that pre-designing and pre-planning class activities serve as a means to scaffold students' cognitive and affective behaviors.

Second, the 5I model implements pacing, procedures, and routines where both the students and teachers understand their roles at every point in time during learning activities. Disruptions in classroom learning often occur when there is no adequate procedures and routines. However, when students understand routines, such as what to do when they get to the classroom, how to get the teacher's attention, and how to transition between learning activities, they are less likely to disrupt the flow of the lesson [55,56]. These proactive classroom management strategies are central to managing constructive social interactions in class while actively engaging the students in the 5I model classroom.

The concern of students being unmotivated to watch the lesson videos, which may have contributed to the underperformance of the students in the conventional flipped classroom, was effectively managed in the 5I model flipped classroom through the provision of incentives. The model offers positive incentive mechanisms at multiple stages of the learning process. The assignment of scores to group presentations and the weekly presentation of the leading group on the school's notice board motivated the winning group to learn more and kept the other groups on their toes, deeply engaged with their learning materials and actively participating in the classroom activities. The qualitative findings conform to this conjecture, as students reported that the classroom activities involving group presentations and scoring of practical tasks motivated them to engage more actively with learning materials, including the lesson videos.

Studies have shown that motivation is a crucial element of effective teaching practices [57,58], driving both the students and the teachers to achieve learning goals and sustaining the interest of the students in learning. Evidence abounds that highly motivated students are readily interested in learning and are likely to perform significantly better than students who are not motivated [58,59]. Moreover, not only do the unmotivated students tend to perform poorly, but they also make the teaching and learning exercise frustrating, as the teacher will repeatedly go over the concepts to ensure students' understanding. This was the case for Nayn, who expressed difficulty in continuing with classroom activities after considering the large number of students who failed to watch the lesson videos.

Additionally, the assignment of pre-class tasks to accompany the pre-class videos and readings in the 5I flipped classroom was noted to have a differential impact on student learning, as this was not a practice in the conventional flipped classroom. Understanding mathematics concepts requires consistent application of principles to solving problems. The pre-class tasks, which are also treated in class, gave the students the opportunity to learn, relearn, practice, and gain a meaningful understanding of the concepts. These opportunities to make cognitive connections with prior knowledge facilitate deeper learning, emphasizing the role of advanced organizers in promoting meaningful learning [41]. This finding supports a previous flipped classroom meta-analysis study [25], which found that the flipped classroom yields robust learning benefits when pre-class videos are accompanied by pre-class tasks for students to engage with.

6. Conclusions and limitations

As the one-size-fits-all model of flipping the classroom faces increasing challenges for effective implementation in African educational contexts, it becomes important to find alternatives that sustainably address challenges and effectively promote meaningful learning. By comparing the effect of the 5I model of flipped classroom and the conventional flipped classroom on mathematics achievement among senior secondary school students in Nigeria, this study established that the 5I flipped model is more effective in teaching and learning mathematics than the conventional flipped classroom. Beyond improving students' achievement, the qualitative findings indicated that students enjoyed learning with this model, as it was perceived to promote their learning engagement, deep inquiry, and critical thinking skills and enhance their knowledge retention through the provision of incentives and the organized structure of the classroom activities.

While both teachers shared a similar perception regarding the effectiveness of the flipped classrooms compared to their commonly used traditional lecture method, the conventional flipped classroom teacher expressed difficulties in effectively engaging the students in the learning process, highlighting students' failure to watch the pre-lesson videos and the disorganized classroom activities as major concerns. These concerns reinforce the important role of incentives and the organized sequence of classroom activities offered by the 5I model of the flipped classroom in enhancing students' active engagement in learning.

Thus, as educators strive to ensure students love and learn mathematics, the 5I flipped model offers potential to achieve desirable learning outcomes. A significant contribution of this study is that, while there are diverse models of implementing the flipped classroom resulting in application and adaptation challenges, the 5I model offers a standardized approach that is adaptable to the African educational context. The rich description of the design and implementation procedure of the model in this study offers guidelines for the replication of the study by other researchers and for practical applications of the model by mathematics practitioners.

However, it is important to recognize the limitations of this study to caution against generalizations of the learning outcomes. One potential limitation of this study is the short duration of the intervention (5 weeks), which is considered not long enough to determine if the interest of students in learning mathematics will be sustained for an academic session and beyond. Given the large population of mathematics students within the study area, the sample size is considerably small, and this places a constraint on the generalizability of the findings. Future research should advance the scope of their study over a longer period of time, for example, a full term with a large sample size. This may help account for the limitation of this study by focusing on only one mathematics concept.

Moreover, it is worth noting that the design of the in-class activities has a limitation regarding the duration of the lesson periods. For a single-period (40 minutes) mathematics lesson, the full exploration of each in-class phase may be constrained by limited timing, which may affect the effectiveness of the overall model. Thus, we recommend that teachers or school administrators assign double periods (80 minutes) for a mathematics lesson when implementing the 5I flipped model.

Author contributions

Adekunle Oladejo: Conceptualization, Methodology, Data Analysis, and Discussion; Taibat Olateju: Writing original draft and the revised manuscript, review and validation. Both authors read and approved the final version of the manuscript for publication.

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

Ethical declaration

Ethical considerations were upheld during the course of the study. Participants’ consents were sought and confidentiality of their information was assured.

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