Enhancing High School Students' Understanding of Mathematics through the Flipped Classroom Approach

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ABSTRACT: *The advancement of technology and the increasing demand to enhance students' mathematics achievement necessitates an innovative learning approach. One such approach is flipped learning, which enables students to actively participate in the learning process and work independently with the assistance of technology. The study assessed how the flipped classroom learning model enhances students' mathematical comprehension. The flipped classroom approach involves students engaging with pre-class video assignments and learning materials, followed by in-class discussions to reinforce the acquired knowledge. This research employed a mixed method with a sequential explanatory approach. The target population was Year 11 students enrolled in a senior high school in Simpang Kanan, Aceh Singkil, Indonesia. A sample size of 22 students was selected for the study. Data collection encompassed administering pre-test and post-test assessments, using a mathematical understanding test as the research instrument, and interviews. The data analysis involved the application of paired t-tests and N-Gain tests. The research findings demonstrated a statistically significant improvement in students' mathematical comprehension following implementing the flipped classroom model ($p<0.005$). The average N-gain value was calculated to be 0.45, indicating a moderate gain in understanding. This study suggests that the flipped classroom could be an alternative method to enhance students' mathematics learning.*

KEYWORDS: **Flipped classroom, mathematics comprehension, senior high school, sequence, and series.**

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1. Introduction

The COVID-19 pandemic has brought about significant transformations in classroom learning. Online or hybrid learning formats have replaced traditional face-to-face instruction. The change affects students' mathematical understanding globally, even more in developing countries like Indonesia. Mathematical understanding is a foundation for developing other mathematical abilities. The current Indonesian curriculum, *Kurikulum Merdeka* (Independent Curriculum), underscores the significance of mathematical understanding in enabling students to comprehend and apply factual information, concepts, principles, operations, and mathematical relationships effectively, accurately, efficiently, and precisely when solving problems. Despite these assertions, research by Dewi and Agustika (2020) revealed that students still exhibit deficiencies in mathematical understanding while studying mathematics in the classroom. Insufficient mastery of mathematical concepts among students often leads to difficulties in solving mathematical problems (Kariadinata et al., 2019).

One area of mathematical concepts that students have not fully grasped is the topic of sequences and series, as reported in some studies in the Indonesian context. The research conducted by Pirmanto et al. (2020) revealed that many students struggle to explain the nature and characteristics of problems related to sequences and geometry. Similarly, Zebua et al. (2020) found that students' ability to comprehend and represent arithmetic sequences and series did not reach their maximum potential. Another study by Wahidah and Hakim (2022) confirmed the persistently low level of mathematical understanding among students regarding the material on sequences and series. Surprisingly,

the issue of understanding sequence and series is also discussed in some studies in other countries, such as a case study conducted by Akgun and Duru (2007) in Turkey. These research findings indicated that students often struggle to correctly understand the problems and determine which formula to employ for problem-solving.

In our preliminary study, we assessed 42 Year 11 students by administering mathematical understanding questions related to sequences and series. The questions focused on two main indicators: the ability to classify arithmetic and geometric sequences based on their properties and the ability to represent arithmetic sequences in various mathematical forms. Upon analyzing the answers, it was evident that the majority of students obtained low scores. This was reflected in their incorrect responses, particularly in classifying arithmetic sequences. Only 31% of students provided accurate answers, demonstrating a clear lack of understanding among most students. Furthermore, it became apparent that many students struggled not only in classifying arithmetic or geometric sequences but also in comprehending the questions correctly. Therefore, the comprehension of sequences and series among students in mathematics poses a significant concern that necessitates considerable attention. An alternative learning model is imperative to tackle this issue effectively.

Students' inadequate understanding of mathematics, including the topic of sequence and series, can be attributed to the prevalent lack of studying at home. Many students tend to allocate more time to Internet activities, such as gaming and watching movies. As confirmed by some studies, students' addiction to gaming has been a global issue; for example, it was revealed by Sung et al. (2020) studied the South Korean context, and Karaca et al. (2022) investigated the students in Turkey. These findings also align with the research conducted by Puspita and Rohedi (2018) in Indonesia, revealing that students prioritize online games and YouTube over educational content on the Internet. This phenomenon is also supported by survey data from the Indonesian Internet Service Providers Association (APJII), indicating that 45% of internet usage among students is dedicated to watching videos. The APJII survey since 2018 also highlights that the age group with the highest percentage of internet users (91%) falls within the 15-19-year-old student category.

The Internet is a double-edged sword. On the one hand, it can hinder students' education, while on the other hand, it can be utilized to captivate students' attention and leverage it to improve their learning. The statistics suggest that Indonesian students are already well-versed in internet usage, which presents an opportunity to integrate technology into the learning process. Linking it to Vygotsky's learning theory, Stahl (2013) emphasized the influence of a child's culture and social environment in shaping their understanding. Therefore, it is possible to cultivate students' understanding by leveraging their existing habits and proficiency with gadgets or other digital tools. Integrating technology with students can provide a viable solution for enhancing learning outcomes. One instructional model that can be implemented is the flipped classroom model, which involves students initially exploring and gathering information from their gadgets.

The flipped classroom is commonly described as a strategy that reverses the traditional educational setting by relocating the information transmission aspect of a conventional face-to-face lecture outside the scheduled class time (Divjak et al., 2022). Similarly, Bergmann and Sams (2012) describe it as a departure from traditional learning, where students receive instructional content during classroom sessions. Instead, students access instructional materials outside the classroom in the flipped classroom. Furthermore, Schallert et al. (2022) assert that the flipped classroom approach involves delivering information outside the classroom and utilizing in-class time for student-centred learning activities. In a simple explanation, the flipped classroom is a blend of face-to-face teaching and online learning.

Implementing the flipped classroom model holds significant importance for teachers as it offers compelling reasons for fostering an effective learning environment. Research

conducted by Cabi (2018) demonstrated that the flipped classroom model provides students ample time to engage in the learning process. Additional findings from Armiati et al. (2019) indicate that incorporating supplementary learning videos can enhance students' ability to learn independently. Algarni and Lortie-Forgues (2023), in their study on Saudi Arabian students, found that the implementation of the flipped classroom received positive feedback from both students and teachers. Moreover, the research conducted by Faridah et al. (2021) revealed that the flipped classroom model promotes better student understanding. Completing assigned tasks before the classroom session gives students a foundational understanding, resulting in a more efficient and productive learning experience.

The flipped classroom model can also improve student understanding of concepts. Based on research by Juniantari et al. (2019) showed that students' mathematical understanding of the flipped classroom learning model was higher than in conventional classes. Furthermore, Widyasari et al. (2021) flipped classroom learning improves student abilities, but in this study, students' critical thinking skills are studied. In addition, Gitadewi et al. (2022) showed that using flipped classroom learning can improve understanding of concepts; this can be seen from the increase in students' pre-test and post-test scores. The research problem addressed in this study is whether flipped classrooms can enhance students' mathematics understanding of sequence and series. The novelty of this research is that it was carried out in Aceh Singkil District, Aceh, Indonesia, one of the regencies farthest from the capital city of Aceh Province; this district has never implemented the flipped classroom model. Another novelty in this study is that researchers provide the same modules and teaching materials to improve students' mathematical understanding.

2. Literature review

2.1 Flipped classroom model

The flipped classroom model is an instructional approach that emphasizes student-centred learning. Unlike traditional classrooms, the flipped classroom model involves students engaging with instructional content through pre-class activities, such as watching video materials provided by the teacher to explore information outside of class. In the classroom, students engage in discussions and problem-solving related to the material they may not have fully grasped (Bart, 2014). The learning process in the flipped classroom model promotes independent learning, where students are responsible for setting their own pace to complete assigned tasks (Baker, 2016). Pre-class instruction through video materials encourages active student participation during in-class activities (Couch & Towne, 2018). Thus, the flipped classroom model involves assigning video materials as learning resources, enabling students to explore their abilities before class and actively participate in discussions to seek clarification on concepts they may not have understood outside of class.

Flipped classrooms have been widely applied in mathematics learning. Demir et al. (2023) found to investigate the mathematical reasoning of secondary school students concerning the concept of circle area using flipped classroom approach. Algarni & Lortie-Forgues (2023), studying Saudi Arabian students, revealed that flipped classroom applications enhance students' self-efficacy but make no significant difference in students' mathematics achievement. Staddon (2022) developed the supported flipped learning model and found that implementing the flipped classroom model assists students with lower self-regulation, particularly those who struggle in flipped learning settings. A systematic review by Cevikbas and Kaiser (2023) concluded that the flipped classroom is a pedagogical approach with potential advantages for mathematics education, with both significant benefits and drawbacks, which can be applied during the pandemic and beyond the crisis era.

Further, a meta-analysis on the implementation of flipped classrooms was conducted by Güler et al. (2023) reported that the impact of the effect sizes was noticeably influenced by the level of education and the specific area of mathematics content. This suggests that the success of applying flipped classrooms in primary school, for example, may differ from those in secondary

school or university students. Other studies also examine flipped classrooms from teachers' perspectives. For example, Toivola et al. (2022) revealed that teachers employed self-paced learning and mathematics learning paths as central practices in their flipped learning approach, guiding students through sequential activities, allowing them to set goals, develop autonomy, and meet competency requirements.

The studies mentioned above show the importance of investigating flipped classrooms and highlight its current trend; examining the implementation of flipped classrooms for students in a remote area, such as in this study, is a promising idea. The results will contribute to discussing the flipped classroom in a different context with distinct student characteristics. In this study, the implementation of the flipped classroom model follows the principles outlined by Bergmann and Sams (2012), which include: (1) introducing the mastery of the flipped classroom model on the first day of instruction, (2) providing information about the model to parents, (3) guiding students on accessing video resources, (4) encouraging students to generate questions, (5) fostering a collaborative environment where students assist one another, and (6) implementing an assessment system to evaluate student progress.

2.2 Mathematics Understanding

Studies related to mathematics understanding have been widely conducted, predominantly focusing on students and some emphasizing teachers' ability to notice or nurture students' understanding. Cai and Ding (2017) discussed the mathematical understanding meaning from the perspective of Chinese teachers explaining mathematical understanding as complex relationships instead of relationships between concepts and procedures. Görgüt and Dede (2020) studied the perspectives of mathematics teachers in assessing students' mathematics understanding. In addition, Ivars et al. (2020) investigated to what extent a learning trajectory assists student teachers in recognizing primary students' mathematics understanding. While Reinke et al. (2022) examined teachers, specifically emphasizing the importance of contextualization to establish a solid foundation for students' understanding of ratios-related mathematical concepts. On the other hand, studies concerning students' mathematical understanding include Zengin (2017), who found utilizing Khan Academy and related mathematics software integrated with flipped classrooms was successful in enhancing students understanding. In addition, Lowrie et al. (2018) designed a framework called ELPSA to enhance students' understanding of mathematics. These recent studies on teachers' and students' mathematical understanding recognize the importance of addressing the fact that teachers play an important role in fostering students' mathematical understanding by upgrading their approach or contextualization.

The definition of mathematics understanding has been variedly defined and contextualized in some studies. It refers to students' capacity to comprehend mathematical concepts, operations, and relationships (Alfeld, 2000). It serves as the foundation for solving mathematical problems encountered in everyday life (Haylock & Cockburn, 2008). Moreover, a comprehensive grasp of mathematics facilitates identifying connections between various concepts (Fennema & Romberg, 2009). Considering the explanations above, mathematical understanding can be perceived as a cognitive process involving internal and external mental activities. It is acquired through comprehending and assimilating concepts and bridging prior knowledge with new knowledge. This present study encompasses specific indicators for assessing the understanding of mathematical concepts, as follows:

The capability to provide examples or non-examples of concepts based on the necessary conditions in an arithmetic sequence (Fennema & Romberg, 2009).

1. The aptitude for expressing concepts using various mathematical representations (Alfeld, n.d.).

2. Proficiency in categorizing specific characteristics following the concept stated in Regulation of the Ministry of Education and Culture of the Republic of Indonesia Number 58 the year 2014 concerning the 2013 Curriculum in junior high schools (Ministry of Education and Culture of the Republic of Indonesia, 2014)

3. The ability to apply concepts to mathematical problem-solving tasks (Haylock & Cockburn, 2008).

4. The skill to apply concepts or algorithms related to arithmetic sequences when solving problems (Alfeld, 2000).

3. Methodology

The theoretical framework underlying this study includes Constructivist Theory and Bloom's Taxonomy (Bloom, 2018). The constructivist theory highlights that students can construct their knowledge while the first three levels of Bloom's taxonomy, classified as lower-order thinking, align with the pre-class stage. In comparison, the in-class stage is more inclined towards the upper three levels of bloom taxonomy. This research utilized a mixed method with a sequential explanatory approach involving pre-test, post-test, and interview. The sample consisted of 22 Year 11 students who received flipped classroom instruction. Considering the research location, being a remote area in Aceh, Indonesia, the senior high school is fairly small, with fewer classes. Thus, in this study, the sample selected was one class available in the school studied. Following implementing the PBL model in the experimental class, a post-test was administered to assess the improvement in students' mathematical understanding across both classes. Interviews were also conducted with students to investigate further the experience of those with medium and low N-gain categories in applying flipped classrooms.

The research instrument employed in this study was a test assessing mathematical understanding and interview guidelines. The tests consisted of eight long answer problems, while the interview guidelines comprised questions to discover further students' experience, including their perception and challenges while participating in the flipped classroom. Furthermore, a comprehensive Lesson Plan, videos, and learning modules specifically designed for the sequences and series content in Year 11 were developed for the learning activities. The data analyzed in this study were derived from the pre-test and post-test results, which were statistically analyzed using paired t-tests and the N-Gain test. The study hypothesizes that implementing the flipped classroom model will lead to an enhanced mathematical understanding among the students in the selected school.

4. Results

The data collected from the research consists of quantitative data regarding the mathematical understanding abilities of the 22 students in the experimental class. The data analysis involved conducting normality and homogeneity tests and employing paired t-tests and the N-Gain test. Based on these tests, the subsequent section analyzes the student's mathematical understanding.

4.1. Descriptive analysis of mathematical understanding

Descriptive statistical analysis was conducted to examine the extent of improvement in students' mathematical understanding through implementing the flipped classroom model. The data collected from the pre-test and post-test scores were subjected to a mean difference test. Before the statistical analysis, a normality test was performed to assess whether the data met the assumptions of normal distribution. If the normality test conditions were satisfied, a paired t-test was conducted.

The results of the normality test for the pre-test and post-test data are presented in Table 1, providing insights into the distribution characteristics of the collected data.

Table 1. Data of normality test based on the pre-test and post-test scores of mathematical understanding

Results	Shapiro-Wilk			Conclusion
	Statistics	Df	p	
Pre-test	.970	22	.718	Ho accepted
Post-test	.931	22	.131	Ho accepted

Table 1 shows the normality test on the pre-test scores of students' mathematical understanding (p=0.718). The null hypothesis (Ho) is accepted,

indicating that the sample originates from a normally distributed population. Similarly, the normality test results for the average post-test scores of students' mathematical understanding (p=0.131). Ho is accepted, indicating that the sample is derived from a normally distributed population. Therefore, the test outcomes demonstrate that the student's pre-test and post-test scores exhibit normal distribution characteristics.

The pre-test and post-test data have met the assumptions for normality, thus enabling the hypothesis-testing process. The paired t-test was employed to examine the extent of improvement in students' mathematical understanding by implementing the flipped classroom model. The research hypothesis is formulated as follows. The paired t-test results for students' mathematical understanding abilities can be seen in Table 2.

$H_{o:}\mu_1=\mu_2$: There is no increase in students' mathematical understanding through the flipped classroom model

$H_{a:}\mu_1>\mu_2$: There is an increase in students' mathematical understanding through the flipped classroom model

The results in Table 2 demonstrate a significant improvement in students' mathematical understanding ability, as evidenced by the rejection of Ho and acceptance of Ha (T=8.8, p=0.00, SD = 17.1). Thus, the research hypothesis, which posits that "There is an increase in students' mathematical understanding through the flipped classroom model," is supported. Consequently, it can be concluded that implementing the flipped classroom model enhances students' mathematical understanding.

4.2. Analysis of increasing students' mathematical understanding

The analysis involved using the N-Gain test to assess the extent of improvement in students' mathematical understanding skills following the implementation of the flipped classroom model. An overview of the N-Gain outcomes is provided in Table 3.

According to the findings presented in Table 3, the average N-Gain score for students' mathematical understanding is 0.45, indicating a medium level of improvement. This increase aligns with the learning objectives of the flipped classroom model, which aim to enhance students' understanding. In this study, students had to watch instructional videos and study modules before in-class mathematics lessons. Subsequently, they engaged in activities such as group discussions, practice exercises, and further exploration of the subject matter during class sessions. These learning approaches facilitated the development of students' mathematical understanding.

During the pre-class phase of the flipped classroom model, teachers play a crucial role in providing instructional materials that students are

Table 2. The results of the paired T-test of students' mathematical understanding

	Paired Differences					T	df	Sig. (2-tailed)
	Mean	Std. Dev	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair Post-test – Pre-test	32.05	17.1	3.64	24.5	39.6	8.8	21	.000

Table 3. Data on the average N-Gain score of students' mathematical understanding

	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
N-Gain_Score	22	-0,22	0.79	0,45	0,252
Valid N (listwise)	22				

expected to engage with outside of the classroom setting. These materials typically take the form of videos and modules, which students can easily access through online platforms or offline resources. Encouraging students to delve into these materials before coming to class allows them to develop their own ideas and understanding of the subject matter. Research conducted by Andamon and Tan (2018) shed light on the benefits of engaging with teaching materials prior to the classroom session. Their findings indicated that this pre-class engagement greatly facilitates the teaching and learning process, benefiting both the teachers and the students. When students are familiar with the instructional materials, classroom time can be utilized more effectively for interactive discussions, problem-solving activities, and collaborative exercises. This active class participation fosters a deeper understanding and retention of mathematical concepts. Similarly, Purwanti et al. (2022) conducted a study in Indonesia that further emphasized the significance of prior exposure to instructional videos in the flipped classroom model. They found that when students are provided with instructional videos as a resource, they have ample time to study and absorb the content at their own pace. This flexibility allows students to revisit the materials multiple times, ensuring a comprehensive understanding of the mathematical concepts taught.

One of the key advantages of using videos as a learning resource is the convenience it offers students. They can access the materials from anywhere and anytime before attending the class. This accessibility empowers students to take control of their learning process and manage their time effectively. Furthermore, it accommodates different learning styles and preferences, as students can pause, rewind, or replay the videos as many times as necessary to grasp the content thoroughly. Providing instructional videos as resources allows students to study and review the content conveniently, enhancing their overall learning experience.

During the flipped classroom model's in-class stage, students and teachers discuss and address any questions or concerns that arise during the pre-class phase. The teacher may briefly revisit the video content shared with students beforehand, allowing students to present their important notes or ask questions related to the modules they studied. The inclusion of videos in the flipped classroom model aims to enhance students' mathematical understanding abilities. This practice aligns with the findings of Ponikwer and Patel (2018), who explored using videos in flipped classroom learning. Their research highlighted that students engaged with video content and completed out-of-class assignments to support their learning outside the classroom. Similarly, research conducted by Latorre-Cosculluela et al. (2021) concluded that integrating videos in the flipped classroom model positively impacts student understanding. By adopting a student-centred approach, where learning activities extend from outside to inside the class, students actively participate in the learning process, contributing to improved comprehension and engagement.

During the in-class stage of the flipped classroom model, students engage in discussions to address any lingering questions or uncertainties that arose during their independent learning outside the classroom. Additionally, students are grouped heterogeneously based on their abilities. In this setting, students collaborate within their groups to work on questions provided in the module, which are aligned with students' mathematical understanding indicators. The assignment given to the groups is designed to promote active participation and collaboration among students. This approach aligns with the findings of a study conducted by Novita et al. (2022), where modules were used as instructional tools to guide students in solving problems during their out-of-class learning. The module is a supportive resource for students, providing clear instructions and guidance throughout their learning process.

The findings of this study align with previous research conducted by Dehghanzadeh and Jafaraghaee (2018), which demonstrated the positive impact of the flipped classroom model on students' cognitive domains, particularly in enhancing their mathematical thinking

skills. This emphasizes the effectiveness of the flipped classroom in promoting higher-order thinking skills and improving students' overall mathematical abilities. Similarly, Hu and Hsu (2018) reported improved higher-order thinking skills among students, indicating that the flipped classroom model can contribute to developing critical thinking and problem-solving abilities. Furthermore, Wei et al. (2020) found that the flipped classroom model positively influenced students' mathematical understanding, further reinforcing the benefits of this approach.

However, the medium-level improvement in students' mathematical understanding skills observed in this study can be attributed to several factors. Firstly, it should be noted that the Aceh Singkil District, where the study was conducted, is located a considerable distance from the provincial capital of Aceh, Indonesia. This geographic distance may have limited exposure to implementing the flipped classroom model in the area, leading to a lack of familiarity and experience among students and teachers. Additionally, the availability of internet access in the district is still suboptimal, posing challenges for students in accessing educational resources such as YouTube. This observation is consistent with the findings of Hastini et al. (2020), who emphasized that inadequate internet networks in certain regions hinder students' access to online learning materials, including instructional videos.

Moreover, the subjects in this study were not accustomed to using YouTube for completing assignments, as they were more accustomed to completing assignments on the same day they were given. This adjustment in learning habits and practices may have influenced their engagement and utilization of the instructional videos. Additionally, the geographical distance between students' homes may have made it challenging for them to interact and engage in collaborative knowledge construction with their peers. This finding aligns with Vygotsky's learning theory, which emphasizes the role of the cultural environment and children's habits in shaping knowledge formation. Vygotsky's collaborative learning theory further asserts that knowledge is constructed through social interaction (Slavin, 2000).

Furthermore, during the implementation of the flipped classroom model, the subjects in this study did not fully optimize their completion of assignments from the module. This could be attributed to their involvement in household chores or other homework tasks upon returning home from school, which may have led to fatigue when watching YouTube videos. As a result, their motivation to complete assignments from the module decreased. Additionally, students in this study preferred direct teacher instruction, as it made them feel happier and more engaged. This finding aligns with the research conducted by Niemi and Kousa (2020), where students voiced concerns about heavy workloads, fatigue, and the potential impact on their learning motivation. Similarly, the research findings of Ozkara and Cakir (2018) indicated that students tend to be more motivated when they have direct communication and interaction with their teachers.

While the flipped classroom model demonstrated a medium-level improvement in students' mathematical understanding skills, several factors may have influenced the outcomes observed in this study. Geographic distance, limited internet access, and students' adjustment to new learning habits and practices played a role in the implementation and effectiveness of the flipped classroom approach. Additionally, students' engagement and motivation were influenced by their involvement in other tasks and their preference for direct teacher instruction. These findings highlight the importance of considering contextual factors, student preferences, and learning habits when implementing the flipped classroom model to optimize its effectiveness in enhancing students' mathematical understanding.

4.3. Subjects' experience in medium and low N-Gain categories in applying flipped classroom.

The Aceh Singkil district where the research was conducted is situated far from the provincial capital of Aceh, Indonesia, and has not previously implemented the flipped classroom

model. The district comprises ten sub-districts, encompassing both land and islands, which may present unique educational access and resource challenges. Considering these contextual factors when interpreting the moderate increase in students' mathematical understanding skills using the flipped classroom model, as evidenced by the n-gain score of 0.45, is essential. However, when considering the Minimum Mastery Criteria (KKM) set by the school, only 5 out of 22 students met the requirements for proficiency.

Several factors contributed to these moderate results. The school under study is the only public upper secondary school serving 24 villages in the district, which indicates limited educational options for students. The challenges related to limited internet availability in the area further hindered students' access to online learning resources, including the materials provided by the researchers. This observation aligns with the findings of Hastini et al. (2020), who highlighted the impact of inadequate internet networks on students' online learning experiences. The lack of familiarity and experience with using YouTube for school assignments among students in the district is also noteworthy. Traditionally, students in the area were accustomed to completing assignments promptly the next day, which indicates a shift in learning habits and practices required for effective engagement with the flipped classroom model. This alignment with Vygotsky's learning theory emphasizes the influence of cultural environments and habits on knowledge formation (Slavin, 2000).

Vygotsky's theory of collaborative learning further explains the importance of collaboration and social interaction in knowledge construction. Students benefit from meaningful interactions with adults and peers who possess more outstanding expertise, as it facilitates the formation of new ideas and enhances intellectual development (Slavin, 2000). The distance between students' homes in the district may have impeded optimal interaction and collaboration among classmates. According to Vygotsky's genetic law of cognitive development, children's growth occurs through social interaction and environmental influences. In implementing the flipped classroom model, the subjects' engagement in exploring information and completing module assignments was not optimal due to their involvement in household chores and fatigue after school. This finding aligns with the research conducted by Niemi and Kousa (2020), where students reported experiencing fatigue and reduced motivation due to heavy workloads.

In the zone of proximal development (ZPD), as conceptualized by Vygotsky, it becomes apparent that some students require scaffolding and guidance to complete tasks while others can independently solve problems. Within the ZPD, children can accomplish tasks with the assistance of experts. However, in this study, there was limited opportunity for students to seek guidance or ask questions at home, as the educational support from those around them was insufficient to provide scaffolding. As a result, the subjects encountered challenges within their zone of proximal development. Moreover, the subjects' preference for direct teaching, as it facilitated more accessible communication and the ability to seek immediate help when faced with difficulties, is in line with the research conducted by Ozkara and Cakir (2018), which concluded that students tend to be more motivated when they have opportunities for direct communication with their teachers.

Data triangulation using technical triangulation in the study revealed that students faced difficulties during discussions due to their limited initial understanding of the topics covered during out-of-class learning. This finding is consistent with the interviews conducted in the low category, indicating that the subjects' utilization of YouTube and modules as learning tools was not optimal. To overcome these challenges and further enhance the success of the flipped classroom model in the Aceh Singkil district, it is crucial to consider strategies that address the limited internet access, provide additional support for students' engagement and interaction, and facilitate effective communication and scaffolding within the ZPD. These considerations can help optimize the implementation of the flipped classroom model and improve students' mathematical understanding skills in the district.

5. Conclusions

The flipped classroom has gained extensive implementation worldwide, spanning various subject areas in mathematics and student levels. Its prominent feature, allowing students to demonstrate independence in learning and flexibility in choosing study times, has proven to be a promising approach during the pandemic. While studies have explored its implementation pre and post-pandemic, limited research exists on using flipped classrooms in remote areas. Thus, this study aims to contribute to the current knowledge by examining its impact on Year 11 students' mathematics understanding in a remote area of Aceh, Indonesia.

This study examines how the flipped classroom contributes to the improvement of Year 11 students' mathematics understanding in a remote area of Aceh, Indonesia. Based on the analysis and discussion presented, it can be concluded that implementing the flipped classroom model significantly increased students' mathematical understanding. The observed improvement in mathematical understanding falls within the medium category, indicating the effectiveness of the flipped classroom approach. Therefore, it can be inferred that the flipped classroom model is a viable instructional strategy to enhance students' mathematical understanding.

However, implementing flipped classrooms in remote areas requires careful considerations such as unstable internet connections, the distance between residents' homes, and students' familiarity with learning platforms like YouTube. Despite the limitations of this study, including a small sample size from a single class, future research should include more schools in remote areas to comprehensively understand the investigated issues. The challenges faced in implementing the flipped classroom in remote areas should not discourage teachers; instead, further research should focus on designing a tailored flipped classroom model that suits remote learners' unique needs and circumstances, utilizing the strengths and advantages of the approach.

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References

Akgun, L., & Duru, A. (2007). Misunderstandings and difficulties in learning sequence and series: A case study. *Research in Mathematical Education*, *11*(1), 75-85.

Alfeld, P. (2000). *Understanding mathematics* [Study guide]. Department of Mathematics, University of Utah. Retrieved on February 2nd 2023 from http://www.math.utah.edu/~alfeld/math.html

Algarni, B., & Lortie-Forgues, H. (2023). An evaluation of the impact of flipped-classroom teaching on mathematics proficiency and self-efficacy in Saudi Arabia. *British Journal of Educational Technology*, *54*(1), 414-435. https://doi.org/10.1111/bjet.13250

Andamon, J. C., & Tan, D. A. (2018). Conceptual understanding, attitude and performance in mathematics of grade 7 students. *International Journal of Scientific & Technology Research*, *7*(8), 96-105.

Armiati, Yerizon, & Niscaya, R. (2019). Flipped classroom-based mathematics learning equipment for students in grade X SMA. *Journal of Physics: Conference Series*, *1317*, 012129. https://dx.doi.org/10.1088/1742-6596/1317/1/012129

Baker, J. W. (2016). The origins of "The Classroom Flip". In J. Overmyer & N. Yestness (Eds.), *Proceedings of the 1st Annual Higher Education Flipped Learning Conference* (pp. 15-24). *The* University of Northern Colorado.

Bart, M. (2014, July). *Blended and flipped: Exploring new models for effective teaching and learning* [Special report]. Faculty Focus. Retrieved on February 10th 2023 from https://goglobal.fiu.edu/_assets/docs/blended-and-flipped-faculty-focus-special-report.pdf

Bergmann, J., & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day* (1st ed.). International Society for Technology in Education.

Bloom, J. (2018). Piaget on equilibration. In U. Muller, J. Carpendale, & L. Smith (Eds.), *The Cambridge Companion to Piaget* (pp. 131-149). Cambridge University Press.

Cabi, E. (2018). The impact of the flipped classroom model on students' academic achievement. *International Review of Research in Open and Distributed Learning*, *19*(3), 202-221. https://doi.org/10.19173/irrodl.v19i3.3482

Cai, J., & Ding, M. (2017). On mathematical understanding: perspectives of experienced Chinese mathematics teachers. *Journal of Mathematics Teacher Education*, *20*, 5-29. https://doi.org/10.1007/s10857-015-9325-8

Cevikbas, M., & Kaiser, G. (2023). Can flipped classroom pedagogy offer promising perspectives for mathematics education on pandemic-related issues? A systematic literature review. *ZDM–Mathematics Education*, *55*(1), 177-191. https://doi.org/10.1007/s11858-022-01388-w

Couch, J. D., & Towne, J. (2018). *Rewiring education: How technology can unlock every student's potential*. BenBella Books.

Dehghanzadeh, S., & Jafaraghaee, F. (2018). Comparing the effects of traditional lecture and flipped classroom on nursing students' critical thinking disposition: A quasi-experimental study. *Nurse Education Today*, *71*(December), 151-156. https://doi.org/10.1016/j.nedt.2018.09.027

Demir, M., Zengin, Y., Özcan, Ş., Urhan, S., & Aksu, N. (2022). Students' mathematical reasoning on the area of the circle: 5E-based flipped classroom approach. *International Journal of Mathematical Education in Science and Technology*, *54*(1), 99-123. https://doi.org/10.1080/0020739X.2022.2101955

Dewi, N. P. W. P., & Agustika, G. N. S. (2020). Efektivitas pembelajaran matematika melalui pendekatan PMRI terhadap kompetensi pengetahuan matematika [The effectiveness of learning mathematics through the RME approach toward the mathematical competence]. *Jurnal Penelitian dan Pengembangan Pendidikan*, *4*(2), 204-214. https://doi.org/10.23887/jppp.v4i2.26781

Divjak, B., Rienties, B., Iniesto, F., Vondra, P., & Žižak, M. (2022). Flipped classrooms in higher education during the COVID-19 pandemic: Findings and future research recommendations. *International Journal of Educational Technology in Higher Education*, *19*, Article 9. https://doi.org/10.1186/s41239-021-00316-4

Faridah, N., Ridlo, S., & Saptono, S. (2021). The influence of flipped classroom learning model application on problem-solving ability and learning motivation. *Journal of Innovative Science Education*, *10*(3), 339-347.

Fennema, E., & Romberg, T. A. (Eds.). (2009). *Mathematics classrooms that promote understanding*. Lawrence Erlbaum Associates.

Gitadewi, A. J., Supardi, Z. A. I., & Maryuni, W. (2022). Student's concept understanding and motivation to learn through flipped classroom learning integrated with nested model. *Studies in Learning and Teaching*, *3*(1), 62-73. https://doi.org/10.46627/silet.v3i1.105

Görgüt, R. Ç., & Dede, Y. (2020). Views of mathematics teachers to evaluate the mathematical understandings of students: SPUR approach. *Necatibey Faculty of Education Electronic Journal of Science & Mathematics Education*, *14*(2), 1475-1503. https://doi.org/10.17522/balikesirnef.700662

Güler, M., Kokoç, M., & Önder Bütüner, S. (2023). Does a flipped classroom model work in mathematics education? A meta-analysis. *Education and Information Technologies*, *28*(1), 57-79. https://doi.org/10.1007/s10639-022-11143-z

Hastini, L. Y., Fahmi, R., & Lukito, H. (2020). Apakah pembelajaran menggunakan teknologi dapat meningkatkan literasi manusia pada generasi Z di Indonesia? [Can learning using technology increase human literacy among Generation Z in Indonesia?] *Jurnal Manajemen Informatika (JAMIKA), 10*(1), 12–28. https://doi.org/10.34010/jamika.v10i1.2678

Haylock, D., & Cockburn, A. D. (2008). *Understanding mathematics for young children*: *A guide for foundation stage and lower primary teachers* (3rd ed.). SAGE Publication Inc.

Hu, C.-F., & Hsu, F.-F. (2018). The value of adding a flipped learning component to a humanities course in higher education: Student perception and performance. *Taiwan Journal of TESOL, 15*(2), 1–32. https://doi.org/10.30397/TJTESOL.201810_15(2).0001

Ivars, P., Fernández, C., & Llinares, S. (2020). A learning trajectory as a scaffold for pre-service teachers' noticing of students' mathematical understanding. *International Journal of Science and Mathematics Education*, *18*, 529-548. https://doi.org/10.1007/s10763-019-09973-4

Juniantari, M., Pujawan, I. G. N., & Widhiasih, I. D. A. G. (2019). Pengaruh pendekatan flipped classroom terhadap pemahaman konsep matematika siswa SMA [The effect of the flipped classroom approach on understanding high school students' mathematical concepts]. *Journal of Education Technology*, *2*(4), 197-204. https://doi.org/10.23887/jet.v2i4.17855

Karaca, S., Karakoc, A., Can Gurkan, O., Onan, N., & Unsal Barlas, G. (2020). Investigation of the online game addiction level, sociodemographic characteristics and social anxiety as risk factors for online game addiction in middle school students. *Community Mental Health Journal*, *56*, 830-838. https://doi.org/10.1007/s10597-019-00544-z

Kariadinata, R., Yaniawati, R. P., Sugilar, H.,& Riyandani, D. (2019). Learning motivation and mathematical understanding of students of Islamic junior high school through active knowledge sharing strategy. *Infinity Journal, 8*(1), 31-42. https://doi.org/10.22460/infinity.v8i1.p31-42

Latorre-Cosculluela, C., Suárez, C., Quiroga, S., Sobradiel-Sierra, N., Lozano-Blasco, R., & Rodríguez-Martínez, A. (2021). Flipped classroom model before and during COVID-19: Using technology to develop 21st-century skills. *Interactive Technology and Smart Education*, *18*(2), 189-204. https://doi.org/10.1108/ITSE-08-2020-0137

Lowrie, T., Logan, T., & Patahuddin, S. M. (2018). A learning design for developing mathematics understanding: The ELPSA framework. *Australian*

Mathematics Teacher, 74(4), 26-31.

Ministry of Education and Culture of the Republic of Indonesia. (2014). Peraturan Menteri Pendidikan dan Kebudayaan Republik Indonesia Nomor 58 Tahun 2014 tentang Kurikulum 2013 SMP/MTS [Regulation of the Minister of Education and Culture of the Republic of Indonesia Number 58 of 2014 concerning the 2013 Middle School/MTS Curriculum]. Retrieved on February 10th 2023 from https://peraturan.go.id/id/permendikbud-no-58-tahun-2014

Niemi, H. M., & Kousa, P. (2020). A case study of students' and teachers' perceptions in a Finnish high school during the COVID pandemic. *International Journal of Technology in Education and Science, 4*(4), 352-369. https://doi.org/10.46328/ijtes.v4i4.167

Novita, R. D., Aminatun, T., & Daryono, R. W. (2022). E-modules through flipped classroom and PBL models on environmental pollution material to increase problem-solving ability. *Journal of Education Technology*, *6*(4), 744-754. https://doi.org/10.23887/jet.v6i4.51656

Ozkara, B. O., & Cakir, H. (2018). Participation in online courses from the student's perspective. *Interactive Learning Environments, 26*(7), 924-942. https://doi.org/10.1080/10494820.2017.1421562

Pirmanto, Y., Anwar, M. F., & Bernard, M. (2020). Analisis kesulitan siswa SMA dalam menyelesaikan soal pemecahan masalah pada materi barisan dan deret dengan langkah-langkah menurut Polya [Analyzing high school students' difficulties in solving problem-solving questions on sequences and series using Polya's steps]. *JPMI (Jurnal Pembelajaran Matematika Inovatif)*, *3*(4), 371-384.

Ponikwer, E., & Patel, B. A. (2018). Implementation and evaluation of flipped learning for delivery of analytical chemistry topics. *Analytical and Bioanalytical Chemistry, 410,* 2263–2269. https://doi.org/10.1007/s00216-018-0892-2

Purwanti, I. T., & Suryawati, E. (2022). Video lectures in online ESL flipped classroom: Effectiveness, students' evaluation and experiences. *European Journal of Educational Research*, *11*(2), 885-898. https://doi.org/10.12973/eu-jer.11.2.885

Puspita, R. H., & Rohedi, D. (2018). The impact of Internet use for students. *IOP Conference Series: Materials Science and Engineering, 306,* 012106. https://doi.org/10.1088/1757-899X/306/1/012106

Reinke, L. T., Stephan, M., Ayan-Civak, R., & Casto, A. R. (2022). Teachers press for contextualization to ground students' mathematical understanding of ratios. *Journal of Mathematics Teacher Education*, *26*, 335-361. https://doi.org/10.1007/s10857-022-09531-w

Schallert, S., Lavicza, Z., & Vandervieren, E. (2022). Merging flipped classroom approaches with the 5E inquiry model: A design heuristic. *International Journal of Mathematical Education in Science and Technology*, *53*(6), 1528-1545. https://doi.org/10.1080/0020739X.2020.1831092

Slavin, R.E. (2000). *Educational psychology: Theory and practice* (6th ed.). Allyn and Bacon.

Staddon, R. V. (2022). A supported flipped learning model for mathematics gives safety nets for online and blended learning. *Computers and Education Open*, *3*(December), 100106 https://doi.org/10.1016/j.caeo.2022.100106

Stahl, G. (2013). Theories of cognition in collaborative learning. In C. E. Hmelo-Silver, C. A. Chinn, C. K. K. Chan, & A. M. O'Donnell (Eds.), *The international handbook of collaborative learning* (pp. 74-90). Routledge.

Sung, Y., Nam, T. H., & Hwang, M. H. (2020). Attachment style, stressful events, and Internet gaming addiction in Korean university students. *Personality and Individual Differences*, *154*(February), 109724. https://doi.org/10.1016/j.paid.2019.109724

Toivola, M., Rajala, A., & Kumpulainen, K. (2022). Pedagogical rationales of flipped learning in the accounts of Finnish mathematics teachers. *Pedagogies: An International Journal*. https://doi.org/10.1080/1554480X.2022.2077341

Wahidah, N., & Hakim, D. L. (2022). Analisis kemampuan representasi matematis siswa materi barisan dan deret aritmatika kelas XII SMA [Analysis of mathematical representation abilities on arithmetic sequences and series for Year 12 students. *Jurnal Didactical Mathematics*], *4*(1), 74-83. https://doi.org/10.31949/dm.v4i1.2038

Wei, X., Cheng, I.-L., Chen, N.-S., Yang, X., Liu, Y., Dong, Y., Zhai, X., & Kinshuk. (2020). Effect of the flipped classroom on the mathematics performance of middle school students. *Educational Technology Research and Development, 68*(3), 1461–1484. https://doi.org/10.1007/s11423-020-09752-x

Widyasari, S. F., Masykur, R., & Sugiharta, I. (2021). Flipped classroom: Peningkatan kemampuan berpikir kritis matematis dan motivasi belajar peserta didik madrasah tsanawiyah [Flipped classroom: Improving mathematical critical thinking skills and learning motivation of Islamic junior high school students]. *Journal of Mathematics Education and Science*, *4*(1), 15-22. https://doi.org/10.32665/james.v4i1.171

Zebua, V., Rahmi, R., & Yusri, R. (2020). Analisis kesalahan siswa dalam menyelesaikan soal barisan dan deret ditinjau dari kemampuan pemahaman konsep matematis [Analysis of student errors in solving sequence and series problems in terms of the ability to understand mathematical concepts]. *Jurnal LEMMA*, *6*(2), 122-133.

Zengin, Y. (2017). Investigating the use of the Khan Academy and mathematics software with a flipped classroom approach in mathematics teaching. *Journal of Educational Technology & Society*, *20*(2), 89-100.