Enhancing Digital Literacy and Science Understanding: The Impact of a Guided Inquiry-Based Flipped Classroom in Elementary Schools

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***Abstract*—This quasi-experimental study investigates the effectiveness of the guided inquiry-based flipped classroom model in enhancing elementary school students' digital literacy and science understanding. The study employed a quasi-experimental, non-equivalent control group design and involved 128 fourth-grade elementary school students. The guided inquiry-based flipped classroom model was proposed, validated by experts, and implemented in science learning. The results indicated that the model significantly improved elementary school students' digital literacy and science understanding. Descriptive analysis revealed that the experimental group demonstrated higher average post-test scores for digital literacy and science comprehension compared to the control group. The Wilcoxon test results showed that the Asym.sig (2-tailed) value was <0.05, confirming that the guided inquiry-based flipped classroom learning model positively influenced students' digital literacy and science comprehension. Similarly, the Mann-Whitney test results (Asym.sig <0.05) indicated significant differences between the experimental and control groups in digital literacy and science understanding. Broader implementation of this model is recommended for future research. Further studies should examine its effectiveness in other subjects beyond digital literacy and science comprehension, such as science literacy, science process skills, and digital skills.**

***Keywords*—flipped classroom, guided inquiry, primary school, students' understanding, digital literacy, science**

I. Introduction

In today's digital era, digital technology plays a crucial role in daily life. The ability to utilize digital technology requires serious attention, as individuals must learn to consume and produce media messages, create and express themselves digitally, and act responsibly online [1]. Digital transformation in education has led to more flexible, engaging, and productive learning experiences [2]. The increasing use of laptops, smartphones, tablets, and other digital devices has fostered a shift towards student-centered learning approaches [3]. These approaches offer broad access to information and flexibility in terms of time and space.

Students need digital literacy skills from an early stage to adapt to ongoing digital transformations. However, digital inequalities persist, as highlighted during the COVID-19 pandemic [4, 5]. This digital divide became especially urgent during this period [6]. Digital literacy serves as a pragmatic solution to address this gap, particularly in elementary education, where it refers to students' ability to complete tasks using Information and Communication Technology (ICT) [7]. Implementing digital literacy in elementary schools can be achieved through ICT-based learning approaches [8].

ICT and digital literacy are fundamental components of 21st-century learning, placing students at the center of the educational process. The flipped classrooms is one such approaches that aligns with 21st-century learning principles [9]. Flipped classrooms have been shown to significantly influence students' self-reported attitudes toward instrumentality, digital literacy, and technology-related anxiety. This model fosters positive attitudes toward technology use [10]. However, challenges remain, including the increased burden of preparation, assessment, and classroom activities. Additionally, teachers may struggle with a trial-and-error approach due to a lack of pedagogical strategies for flipped classroom implementation [11].

To address these challenges, the flipped classroom model must be integrated with other effective learning models. Inquiry-based learning is particularly suitable for developing digital literacy [12]. Inquiry learning encourages cognitive engagement, critical thinking, and problem-solving, making it ideal for digital literacy instruction [13]. Inquiry-based learning can be structured into various formats, from teacher-directed guided inquiry to student-directed open inquiry [14]. Guided inquiry, in particular, is effective for primary school students, as it supports conceptual knowledge development in science education [15]. Building on the strengths of both models, this study proposes a guided inquiry-based flipped classroom model designed to enhance both digital literacy and science understanding. This model aims to bridge the theoretical gaps in previous studies by integrating structured cognitive frameworks within flipped classrooms to support deeper inquiry and critical thinking. Additionally, it provides a clear pedagogical framework for elementary school teachers implementing digital literacy programs.

Many students struggle with science comprehension due to passive learning experiences and the rote memorization of scientific facts [16, 17]. The guided inquiry-based flipped classroom model seeks to foster active engagement, enabling students to explore scientific concepts in a meaningful way [18]. The novelty of this study lies in the integration of the flipped classroom model with guided inquiry, resulting in a systematic and easy-to-implement instructional design.

This learning model consists of two main phases: the pre-class phase (watching educational videos at home) and the classroom phase, which includes five stages: preparation, hypothesis formulation, research, communication of research, and reflection and judgement. This structured approach represents a significant improvement over previous flipped classroom models.

This study addresses the following research questions:

1) How effective is the guided inquiry-based flipped classroom model in improving elementary school students' digital literacy?
2) How effective is the guided inquiry-based flipped classroom model in enhancing students' understanding of science?

II. Literature Review

A. Digital Literacy in Elementary Education

Over the past few decades, digitalization as a core driver of the Fourth Industrial Revolution, impacting organizations, economies, and individuals' lives [19]. The discussion around 21st-century skills, digital skills, digital competencies, digital literacy, electronic skills, and internet skills has gained significant traction [20]. The development of digital literacy is essential for young people and the communities in which they live [21]. Digital literacy is a specific competency that enables students to understand and utilize digital technology effectively [22], emphasizing the need for critical thinking skills [23]. Strong digital competence allows students to acquire, interpret, and comprehend online information effectively [24].

The digital divide has surfaced as a major obstacle due to individuals' inability to utilize ICT effectively [25]. The COVID-19 pandemic necessitated a shift in educational models, with various countries implementing diverse online learning modalities to bridge this divide [26]. Challenges associated with digital literacy during the pandemic included a lack of technology skills, difficulty in evaluating online information, challenges in online communication, and limited access to library resources. Internal challenges also arose, such as emotional distress experienced by students during the pandemic [27].

Addressing digital literacy challenges in education must be a priority for national education technology digitalization initiatives [28]. Integrating technology into education provides numerous opportunities to enhance digital literacy. Efforts to improve students' digital literacy skills include incorporating structured digital literacy learning into curricula and integrating digital literacy with the broader educational process. Teachers can also employ specific learning models to foster digital literacy [29]. The goal of digital literacy education is to increase student participation in digital media and cultivate active, creative, productive, and innovative individuals [8].

B. Flipped Classroom Model and Science Education

Flipped classroom learning is recognized as an effective approach for enhancing *student learning outcomes [30].* As a subset of blended learning, flipped classrooms provide students with learning resources outside the classroom via virtual platforms. Classroom sessions are then dedicated to brainstorming, problem-solving, and active learning facilitated by teachers [31]. The flipped classroom methodology represents a significant advancement in active learning approaches in virtual environments. However, some students express dissatisfaction regarding teacher involvement and the structured implementation of this methodology [32]. In a flipped classroom, traditional learning structures are reversed. Students engage with learning materials before class, while class time is reserved for higher-order cognitive activities in a group setting [33]. Classroom activities include answering questions, providing feedback, and reinforcing key concepts.

The implementation of flipped classroom elementary science education remains underexplored [9]. Effective science education at the primary level fosters students' understanding of natural phenomena, increases curiosity, and motivates them to become active thinkers [34]. *Elementary school is* a crucial period for developing a positive perception of science [35]. Teachers play a pivotal role in guiding the learning process and must be well-equipped with knowledge of science fundamentals, learning strategies, and curriculum structures [36]. In many countries, the flipped classroom model has become a popular teaching approach for science education [37]. Research indicates that flipped classrooms *improve students' academic performance, satisfaction, engagement, and learning motivation [38].* The model fosters student-centered learning, with students engaging in pre-class activities before participating in interactive classroom experiences, while teachers assume the role of facilitators [39].

C. Guided Inquiry-Based Learning and Science Education

Science plays a critical role in the advancement of technology and scientific knowledge. Through science education, students develop critical thinking and problem-solving skills [30]. Effective science learning helps students refine their understanding of nature and natural processes [31]. Early science education is crucial for several reasons: (1) it fosters the development of new ideas, (2) it clarifies students' existing concepts through scientific evidence, (3) it prevents conceptual misunderstandings by engaging students in scientific experiences, and (4) it promotes positive attitudes toward science.

Science learning can often be complex and challenging, leading to student disinterest [32]. One major issue in science education is the emergence of negative emotions and experiences related to learning [33]. Many students lack opportunities to discover scientific knowledge independently [9]. Traditional science education relies heavily on textbooks, with minimal intrinsic motivation for students to explore beyond the curriculum. Classroom science learning strategies should focus on fostering creativity and curiosity in future generations [29]. Additionally, integrating technology into science education provides more opportunities for engagement [28].

Researchers recommend incorporating ICT into science teaching and learning [34]. The Organisation for Economic Co-operation and Development (OECD) report on innovation in education highlights the importance of technology in science education to enhance both content and procedural knowledge [35]. Recently, flipped classrooms have been recognized as a student-centered learning approach that leverages technology [36]. The effectiveness of flipped classrooms can be further enhanced by integrating inquiry-based learning [37].

Inquiry-based learning is effective for improving students' conceptual understanding of science while increasing motivation and interest [38]. This approach encourages students to engage in authentic scientific discovery by following teacher-guided methods to construct knowledge [39]. Teachers play a crucial role in science education, particularly in the early years [40]. Although inquiry-based learning is essential for developing higher-order thinking skills, research on its implementation within flipped classroom scenarios in science and mathematics education remains limited [41]. Therefore, further investigation is needed to determine whether integrating inquiry-based learning into the flipped classroom model enhances elementary students' science comprehension.

D. The Synergy of Guided Inquiry-Based Flipped Classroom Model: Enhancing Digital Literacy and Science Understanding

Previous studies have explored flipped classrooms in combination with inquiry-based learning. Research on implementing the Inquiry-Based Flipped Classroom (IB-FC) model in primary schools has demonstrated positive experiences and perceptions among teachers, students, and parents [42]. The integration of a flipped classroom with Inquiry-Based Mathematics Education (IBME) has been shown to encourage active learning and interactivity [43]. Additionally, research on the impact of the inquiry-flipped classroom model on student achievement has revealed significant improvements in learning outcomes. Students engaged in inquiry-based flipped classrooms performed better than those following traditional guided inquiry models [44]. The flipped classroom approach within guided inquiry learning has also been linked to enhanced creative thinking in science education [45].

For elementary education, studies focus on the flipped classroom model as a means to facilitate student-centered inquiry-based learning and foster higher-order cognitive skills [42]. Other research has proposed universal design principles for integrating the Flipped Classroom (FC) approach with Inquiry-Based Learning (IBL) to enhance primary education pedagogy [46]. Three key themes in implementing flipped classrooms for primary science learning have been identified: abilities, aids, and challenges [47]. While flipped classrooms offer several advantages for teachers, challenges must be addressed to ensure effective implementation.

Although studies have examined the integration of flipped classrooms and guided inquiry, limited research explicitly evaluates their effectiveness in improving digital literacy and science comprehension in elementary schools. This study seeks to develop a guided inquiry-based flipped classroom model, which will be validated by experts. Following revisions based on expert feedback, the model will be implemented in real-world settings to assess its practicality and effectiveness.

The guided inquiry-based flipped classroom model proposed in this study differs from previous designs [43, 48–51]. The 5E-based flipped classroom framework incorporates five learning phases—Engagement, Exploration, Explanation, Elaboration, and Evaluation—structured across pre-class and in-class activities [46]. Other models divide learning into individual and group spaces, using multimedia tools and screencasting to link pre-class activities to classroom discussions [40].

This study aims to refine and adapt the guided inquiry-based flipped classroom model by integrating the six key major steps of guided inquiry [52] into the flipped classroom framework [53]. This innovative model is expected to enhance students' digital literacy and science understanding more effectively than existing approaches. The integration of the flipped classroom model and the guided inquiry model in this study is presented in Fig. 1.

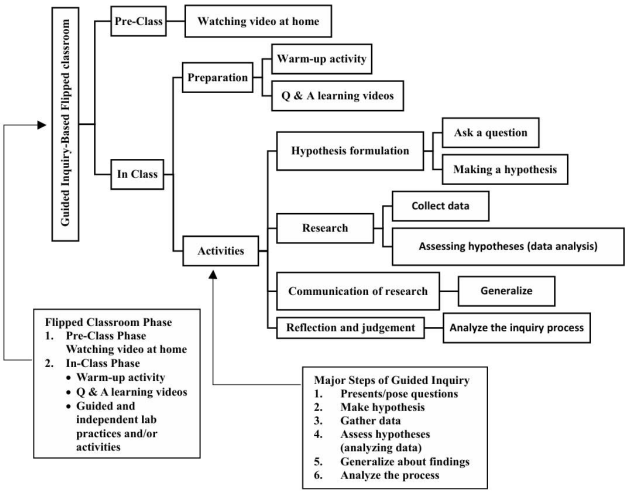

Fig. 1. Guided inquiry-based flipped classroom model.

III. MATERIALS AND METHODS

A. Research Design

This study employs a quasi-experimental, non-equivalent control group design. Data collection was conducted using tests, observations, and questionnaires. The research instruments, including tests, observation sheets, and questionnaires, were validated by experts and revised to ensure their validity and reliability. The research design is outlined in Table 1.

Table 1. Research design

Groups	Pre-test	Treatment	Post-test
Experimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

O_1: Pre-test; O_2: Post-test; X_1: Guided inquiry-based flipped classroom model; X_2: Conventional learning.

B. Participants

Sample selection was conducted using a cluster random sampling technique. The study involved fourth-grade elementary school students from six public schools. The samples were randomly assigned to determine the experimental and control groups. A total of 128 students were selected, with 64 students assigned to the experimental group, where they experienced the guided inquiry-based flipped classroom learning model. Meanwhile, the remaining 64 students in the control group were taught using the conventional learning model.

C. Measurements

Data collection in this study utilized a digital literacy test and a science comprehension test. The digital literacy test was designed to assess the digital literacy skills of fourth-grade elementary school students. These tests were validated by experts in educational research and evaluation before implementation. The instruments for the digital literacy test are shown in Table 2.

Table 2. Test instruments for digital literacy

Indicators	Item
Knowledge of terms, functions, and types of hardware	1, 2, 3
Knowledge of terms, functions, and types of software	4, 5, 6
Knowledge of terms, functions, and types of online tools	7, 8, 9
Knowledge of browser types and tips for using browsers	10, 11
Knowledge of different ways to access information online	12
Understand the steps to search for information on the Internet	13
Understanding security in using the internet	14
Understanding online communication etiquette	15
Understand how to store information from the Internet	16
Understand what information is and should not be accessed	17

In addition to the digital literacy test, a science comprehension test focused on Energy concepts was developed. This test comprises thirteen questions. The details of the test instruments for science comprehension are provided in Table 3.

Table 3. Test instrument for science comprehension

Indicators	Item
Knowledge of energy	1, 2
Knowledge of how humans produce forms of energy	3
Knowledge of energy transformation	4, 5, 9, 13
Knowledge of potential energy	6, 7, 8
Knowledge of kinetic energy	10, 11, 12

D. Data Analysis

The data analysis in this study involved several stages:

1) Analysis of the validity of question items

Validity analysis was conducted to determine the validity criteria of the question items by calculating the correlation coefficient using the Pearson product-moment method. The obtained r-value was then compared with the critical r-value from statistical tables. A question item was deemed valid if its r-value exceeded the critical r-value.

2) Descriptive analysis

Descriptive analysis was performed to summarize the results of the digital literacy test and students' science comprehension. The test scores were tabulated and presented using graphical representations.

3) Model effectiveness test

The effectiveness of the model was assessed to determine whether the guided inquiry-based flipped classroom model had a significant impact on student learning outcomes. A t-test was conducted if the data met the normality assumption. If the data did not meet the normality assumption, a non-parametric statistical test was used instead.

IV. Result and Discussion

After completing the learning process, groups of students from the experimental and control classes were given post-tests to assess their digital literacy and understanding of science concepts. The pre-test and post-test data for both groups were analyzed through the following stages.

A. Results

1) Analysis of the validity of question items

A team of experts in the field of mathematics education assessment validates the test based on four criteria: (1) the alignment of items with indicators, (2) ease of understanding, (3) proper language and spelling, and (4) conceptual accuracy. The digital literacy test consisted of seventeen multiple-choice questions and was administered to 30 fourth-grade elementary school students from one school. Table 4 shows that the digital literacy test is valid, as the r_xy values are greater than the r_table value of 0.361 at a significance level of 0.05. Meanwhile, Cronbach's alpha value is 0.846, indicating high reliability.

Table 4. Item validity of digital literacy test

Items	r_{xy}	r_{table}	Criteria
Item1	0.536	0.361	Valid
Item2	0.446	0.361	Valid
Item3	0.536	0.361	Valid
Item4	0.455	0.361	Valid
Item5	0.657	0.361	Valid
Item6	0.363	0.361	Valid
Item7	0.646	0.361	Valid
Item8	0.432	0.361	Valid
Item9	0.622	0.361	Valid
Item10	0.571	0.361	Valid
Item11	0.601	0.361	Valid
Item12	0.453	0.361	Valid
Item13	0.566	0.361	Valid
Item14	0.617	0.361	Valid
Item15	0.582	0.361	Valid
Item16	0.521	0.361	Valid
Item17	0.548	0.361	Valid

Similarly, a team of experts in science education validated the science comprehension test. After undergoing revisions, the test was administered to 30 fourth-grade elementary school students. Table 5 indicates that all thirteen items are valid, as their r_xy values exceed the r_table value of 0.361. The science comprehension test on the topic of Energy was found to be reliable, with a Cronbach's alpha value of 0.846 at a 0.05 significance level.

Table 5. Item validity of digital literacy test

Items	r_{xy}	r_{table}	Criteria
Item1	0.551	0.361	Valid
Item2	0.605	0.361	Valid
Item3	0.677	0.361	Valid
Item4	0.573	0.361	Valid
Item5	0.583	0.361	Valid
Item6	0.584	0.361	Valid
Item7	0.558	0.361	Valid
Item8	0.704	0.361	Valid
Item9	0.687	0.361	Valid
Item10	0.570	0.361	Valid
Item11	0.696	0.361	Valid
Item12	0.487	0.361	Valid
Item13	0.462	0.361	Valid

2) Descriptive analysis

Descriptive statistics were used to compare the average pretest and posttest scores of students taught using a guided inquiry-based flipped classroom model. Table 6 presents these results.

Table 6 shows that the experimental group's average post-test score for digital literacy ($M = 81.44$) was higher than its pre-test score ($M = 68.55$). In the control group, the post-test score ($M = 70.67$) was also higher than the pre-test score ($M = 67.50$). Similarly, the experimental group's average post-test score for science comprehension ($M = 79.95$) was higher than its pre-test score ($M = 63.70$), and the control group's post-test score ($M = 71.36$) was higher than its pre-test score ($M = 64.66$). These results indicate a difference in average test scores between the experimental and control groups for both digital literacy and science concept understanding.

Table 6. Descriptive analysis of digital literacy and science concept understanding

Dependent Variables	Groups	N	Mean	Std. Deviation
Digital Literacy	Pre-test Experimental	64	68.55	11.506
	Post-test Experimental		81.44	11.067
	Pre-test Control	64	67.50	12.313
	Post-test Control		70.67	10.308
Science Concept Understanding	Pre-test Experimental	64	63.70	9.360
	Post-test Experimental		79.95	9.454
	Pre-test Control	64	64.66	13.770
	Post-test Control		71.36	16.986

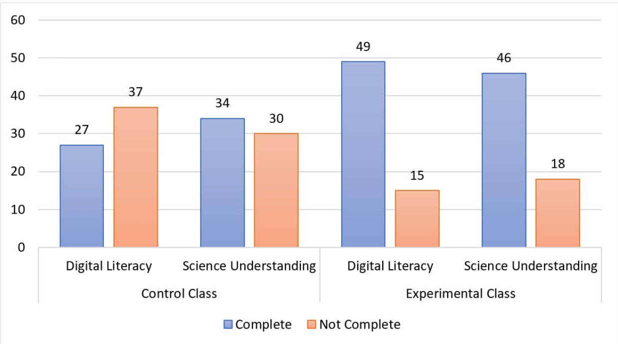

Fig. 2. Learning outcome tests.

Fig. 2 presents a diagram of students' post-test results for digital literacy and science comprehension in the control and experimental classes. Based on a set competency criterion of 75, 49 students (77%) in the experimental class scored ≥75 on the digital literacy test, while 15 students (23%) scored <75. For science comprehension, 46 students (72%) scored ≥75, whereas 18 students (28%) scored <75. In the control class, only 27 students (42%) scored ≥75 on the digital literacy test, while 37 students (58%) scored <75. Similarly, 34 students (53%) scored ≥75 on the science comprehension test, while 30 students (47%) scored <75. These results suggest that the experimental class outperformed the control class, indicating the effectiveness of the guided inquiry-based flipped classroom model.

3) Model effectiveness test results

a) Normality test

The normality test determined whether the research data was normally distributed. If the significance value is >0.05, the data meets the normality assumption; otherwise, it does not. The normality test results for both digital literacy and science comprehension indicated that the data was not normally distributed. Therefore, nonparametric statistical tests were used for further analysis.

b) Homogeneity test

The homogeneity test examined whether the post-test data from the control and experimental classes had equal variance. If the significance value is >0.05, the data is homogeneous; otherwise, it is not. The results showed that the digital literacy test data was homogeneous, whereas the science comprehension test data was not. Since normality and homogeneity requirements were not met for science comprehension, nonparametric statistical methods were used for analysis.

c) Wilcoxon test

The Wilcoxon test was conducted to assess differences between pre-test and post-test scores. The hypotheses tested were:

H1: There is a significant difference in students' digital literacy before and after learning with the guided inquiry-based flipped classroom model.

H2: There is a significant difference in students' science comprehension before and after learning with the guided inquiry-based flipped classroom model.

The Wilcoxon test results for digital literacy are shown in Table 7.

Table 7. Wilcoxon test results for digital literacy

Test Statistics[a]	
	Post-Test - Pre-Test
Z	−6.261[b]
Asymp. Sig. (2-tailed)	0.000

[a] Wilcoxon signed ranks test; [b] Based on negative ranks.

Since Asymp. Sig. <0.05, the hypothesis is accepted, indicating that the flipped classroom model significantly improved students' digital literacy.

The Wilcoxon test results for science comprehension are shown in Table 8. Similarly, Asymp. Sig. <0.05 confirms that the model significantly enhanced students' understanding of science concepts.

Table 8. Wilcoxon test results for science comprehension

Test Statistics[a]	
	Post-Test - Pre-Test
Z	−6.603[b]
Asymp. Sig. (2-tailed)	0.000

[a] Wilcoxon signed ranks test; [b] Based on negative ranks.

d) Mann-Whitney test

The Mann-Whitney test compared the post-test scores of the experimental and control groups. The Mann-Whitney test results for digital literacy are shown in Table 9.

Table 9. Mann-Whitney test results for digital literacy

Test Statistics[a]	
	Digital Literacy Learning Outcomes
Mann-Whitney U	1057.500
Wilcoxon W	3137.500
Z	−4.771
Asymp. Sig. (2-tailed)	0.000

[a] Grouping variable: Class.

Table 10. Mann-Whitney test for science comprehension

Test Statistics[a]	
	Science Learning Outcomes
Mann-Whitney U	1415.000
Wilcoxon W	3495.000
Z	−3.024
Asymp. Sig. (2-tailed)	0.002

[a] Grouping variable: Class.

Since Asymp. Sig. <0.05, a significant difference exists between the experimental and control groups in digital literacy.

Again, since Asymp. Sig. < 0.05, a significant difference exists in students' understanding of science between the two groups. The Mann-Whitney test results for science comprehension are shown in Table 10.

B. Discussion

The effectiveness of the guided inquiry-based flipped classroom model demonstrates the advantages of integrating these two instructional approaches. The flipped classroom has several benefits [54]: including improved learning outcomes, self-paced learning through videos, and flexible access to content in terms of time and place. Additionally, this model allows teachers to engage directly with students, fostering deeper teacher-student relationships. In collaborative learning with teacher guidance, the flipped classroom approach supports peer and teacher-student interconnectedness [55]. However, despite its benefits, concerns remain regarding the potential for the flipped classroom model to widen the digital divide [56] as students with access to digital devices may outperform those without.

The digital divide has become more pronounced during the pandemic. As a result, teachers must receive adequate training to improve their digital competencies and specialized skills in order to effectively implement innovative pedagogical programs [26]. Among these innovative approaches is IBL, which encourages students to think critically, analyze, synthesize, conduct research, evaluate, and reflect [57]. A positive correlation exists between inquiry-based learning and digital literacy [13] can be incorporated into the learning process using the inquiry cycle [12].

In addition to fostering digital literacy, guided inquiry-based learning enhances students' science learning outcomes [51]. Students with lower pretest scores particularly benefit from guided inquiry due to structured teacher guidance [52]. Inquiry-based learning also creates a supportive environment for innovative teaching strategies that assess students' learning progress [53]. The guided inquiry model encourages students to actively engage with various sources of information to deepen their understanding of concepts [18]. Additionally, the model accommodates different cognitive styles, which can significantly impact student achievement [51].

Motivating students is a crucial factor in designing and implementing learning activities [58]. The characteristics of the guided inquiry-based flipped classroom model positively influence student motivation. Research indicates that flipped learning increases students' motivation, self-efficacy, conceptual understanding, and attitudes toward learning [59]. Students in flipped classrooms feel motivated, eager to explore, and aware of their learning responsibilities [2]. Inquiry-based learning also enhances students' interest in science, supports inquiry skills and conceptual understanding, and inspires teachers in science education. Effective science teaching fosters curiosity and encourages students to explore the world actively and critically. Previous studies supported the effectiveness of the guided inquiry-based flipped classroom model. Five key studies on this model have been reviewed, and their findings have been analyzed to refine the proposed model framework: flipped classroom based on guided inquiry.

First, a study integrated Knowledge Management (KM) and inquiry-based approaches into the flipped classroom [43]. This study used an experimental method with 51 students enrolled in a programming course. The findings indicate that integrating KM and inquiry-based approaches can enhance student learning and improve learning outcomes. The study proposed a flipped classroom environment incorporating an out-of-class learning system and an in-class management system that implements KM and includes a teacher management system. The research also recommended developing tools to assist teachers in future studies. Additionally, further research is needed to explore student behavior, learning interests, and learning sustainability when applying the KM model with a mixed inquiry-based flipped classroom approach.

Second, a multi-case study explored the flipped classroom model for inquiry-based learning in elementary schools [49]. This research involved schools, teachers, and students, finding that teachers, students, and parents generally had positive experiences and perceptions. Students were satisfied with FC activities, enjoyed the flipped learning approach, and agreed that classroom interaction through IBL activities was crucial for their understanding. Both students and teachers found FC activities more engaging due to the integration of technology. The inquiry-based flipped classroom model proposed in this study consists of two stages: an individual learning space (at home) and a group learning space (in class). The study proposed universal design principles based on practical implementation suggestions derived from student, teacher, and parent experiences, as well as relevant literature. It recommended future research on the implementation of the new IB-FC model based on universal design principles in K-12 education.

Third, design-based research was conducted with 22 secondary mathematics teachers [48]. The findings demonstrated that a heuristic design based on the 5E inquiry model supports teachers in planning inquiry-based flipped classroom lessons. This study proposed a heuristic design for 5E-based flipped classroom scenarios. The five inquiry phases—engagement, exploration, explanation, elaboration, and evaluation—were incorporated into the flipped classroom structure, with distinct out-of-class and in-class activities. The study recommended further research to test the model's effectiveness in other subjects.

Fourth, a study conducted with 11th-grade students employed the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model [51] to assess their ability to implement Control Variable Strategies (CVS) while engaging with inquiry-based worksheets during the COVID-19 era. The results indicated that students were able to adopt the flipped classroom approach through synchronous and asynchronous sessions. The inclusion of probe questions in digital Worksheets (e-WS), combined with explicit references, increased students' awareness of scientific practices and their ability to apply the CVS. The implementation scheme consisted of three phases: Phase 1 (students study materials at home), Phase 2 (students complete the digital worksheet), and Phase 3 (students discuss the completed worksheet in class). The researchers recommended expanding the application of inquiry-based worksheets beyond high school students to include junior high school students.

Fifth, a case study on inquiry-based linear algebra learning within the flipped classroom framework was conducted with engineering students [50]. Inquiry-Based Mathematics Education (IBME) has been shown to encourage active learning and increase classroom interactivity. The FC approach has proven effective in supporting IBME. Its core principles include (1) computer-assisted individual learning outside the classroom through video instruction and (2) interactive group learning activities within the classroom. A key advantage of FC is its ability to enhance classroom teaching quality by allowing for an in-depth exploration of mathematical concepts. The combination of FC and IBME classroom activities is referred to as the Flipped Inquiry-Based Mathematics Education (FIBME) design. The researchers recommended increasing the number of learning sessions to six, as the two sessions used in this study were insufficient for comprehensive learning.

Among the five reviewed studies, only one focused on elementary school students, while the others were conducted in college and high school settings. All five studies consistently incorporated the flipped classroom's out-of-class and in-class phases but integrated inquiry-based learning in different ways. The first study added Knowledge Management, the second explored flipped classrooms in a multi-case study, the third introduced a heuristic 5E inquiry design, the fourth used e-worksheets, and the fifth combined flipped classrooms with IBME.

The guided inquiry-based flipped classroom model proposed in this study is more straightforward than the five existing models, making it more suitable for elementary school implementation. The model combines the two phases of the flipped classroom with six major steps of guided inquiry, making it novel in its application to elementary school science education. Additionally, previous research has not examined the effectiveness of this model in improving digital literacy and science understanding. A comparison with previous research can be seen in Table 11 below.

Table 11. Comparison of previous models with proposed models

No	Model Name	Model Uniqueness	Method, Sample, Subject
Previous models			
1	Knowledge Management (KM) Model Blended Inquiry Flipped Classroom Approach	Implements Knowledge Management within a flipped classroom	Experimental, Higher education, Web-Programming
2	Inquiry-Based-The Flipped Classroom (IB-FC)	Flipped Classroom model with universal design principles	Multi case-study, Elementary Schools, Science
3	Inquiry-Based Flipped Classroom Scenarios	Incorporates the 5E Inquiry Model into flipped learning	Design-based research, Secondary Math teachers, Mathematics
4	Inquiry-Based Worksheets	Assesses students' ability to apply Variable Control Strategies	ADDIE model, Grade 11, Science
5	Flipped Inquiry-Based Mathematics Education (FIBME)	Combines flipped classroom with IBME framework	Case study, Engineering students, Mathematics
Proposed Models			
	Guided Inquiry-Based Flipped Classroom Model	Combines flipped classroom phases with six guided inquiry steps	Quasi-experimental, Primary school, Science

Despite its contributions, this study has limitations, including a restricted sample of fourth-grade students and a focus solely on science subjects. However, it fills a gap in the literature by complementing prior research with a quasi-experimental approach. The methodology used in previous studies includes experimental, design-based research, multi-case studies, case studies, and ADDIE, whereas this study applies a quasi-experimental design. Furthermore, by focusing on fourth-grade students, this study expands the range of educational levels explored in flipped classroom and inquiry-based learning research. This study also distinctly defines guided inquiry as an integrated model within flipped classrooms, differentiating it from previous work.

V. CONCLUSION

This study aimed to evaluate the effectiveness of the guided inquiry-based flipped classroom model in enhancing elementary school students' digital literacy and science comprehension. A quasi-experimental, non-equivalent control group design was employed, involving 128 students from six elementary schools. The guided inquiry-based flipped classroom model was developed and validated by experts before its implementation. The model consists of two main phases: the pre-class phase, where students watch instructional videos at home, and the classroom phase, which includes five stages: preparation, hypothesis formulation, research, communication of research, and reflection and judgement.

Descriptive analysis revealed that the experimental group achieved a higher average post-test score in digital literacy (M = 81.44) compared to their pre-test score (M = 68.55). Similarly, the control group's post-test score (M = 70.67) was higher than their pre-test score (M = 67.50). For science comprehension, the experimental group's post-test score (M = 79.95) exceeded their pre-test score (M = 63.70), while the control group's post-test score (M = 71.36) was higher than their pre-test score (M = 64.66). These findings indicate a difference in average test scores between the experimental and control groups, with the experimental group demonstrating greater improvement in both digital literacy and science comprehension.

The Wilcoxon test results for digital literacy showed an Asymp. Sig (2-tailed) value <0.05, confirming that the guided inquiry-based flipped classroom model significantly influenced students' digital literacy. Similarly, the Wilcoxon test for science comprehension yielded an Asymp. Sig (2-tailed) value <0.05, indicating that the model positively impacted students' science comprehension. The Mann-Whitney test was used to compare post-test scores between the experimental and control groups. The results showed that the Asymp. Sig (2-tailed) value was <0.05 for both digital literacy and science comprehension, confirming a significant difference between the two groups.

Based on the findings from descriptive analysis, the Wilcoxon test, and the Mann-Whitney test, it can be concluded that the guided inquiry-based flipped classroom model effectively improves students' digital literacy and science comprehension. Future research is recommended to expand the implementation of this model. In this study, the sample was limited to fourth-grade elementary school students. Further research can explore the model's effectiveness in other grade levels and subject areas beyond digital literacy and science comprehension. Potential areas of investigation include science literacy, science process skills, and digital skills.

APPENDIX

Normality test results are in Table A1 and Table A2.

Table A1. Normality of the digital literacy test

Tests of Normality							
	Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Student Learning Outcomes	Pre-Test Experiment	0.162	64	0.000	0.907	64	0.000
	Pos-Test Experiment	0.157	64	0.000	0.934	64	0.002
	Pre-Test Control	0.128	64	0.011	0.957	64	0.025
	Post-Test Control	0.146	64	0.002	0.940	64	0.004

[a] Lilliefors significance correction.

Tabel A2. Normality of the science comprehension test

Tests of Normality							
	Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Student Learning Outcomes	Pre-Test Experiment	0.217	64	0.000	0.857	64	0.000
	Pos-Test Experiment	0.144	64	0.002	0.891	64	0.000
	Pre-Test Control	0.233	64	0.000	0.846	64	0.000
	Post-Test Control	0.146	64	0.002	0.951	64	0.013

[a] Lilliefors significance correction.

Homogeneity test results are in Table A3 and Table A4.

Table A3. Homogenity of the digital literacy test

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Student Learning Outcomes	Based on Mean	0.010	1	126	0.920
	Based on Median	0.011	1	126	0.917
	Based on Median and with adjusted df	0.011	1	121.309	0.917
	Based on trimmed mean	0.009	1	126	0.924

Table A4. Homogeneity of the science comprehension test

Test of Homogeneity of Variance					
		Levene Statistic	df1	df2	Sig.
Student Learning Outcomes	Based on Mean	27.354	1	126	0.000
	Based on Median	16.346	1	126	0.000
	Based on Median and with adjusted df	16.346	1	95.415	0.000
	Based on trimmed mean	27.168	1	126	0.000

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

AW conducted the field research and drafted the initial paper; SIAD provided guidance on research and development, as well as reviewed the background, literature review, and methodologies; BS contributed advice on research and development, reviewed the results, and participated in discussions; all authors had approved the final version.

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