Human Behavior, Development and Society
E-ISSN 2651-1762, Vol 26 No 1, April 2025

The Effects of Blended Learning Management in Earth Science on Learning Achievement and Digital Skills of Grade 4 Students at Ekamai International School

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Date Received: 15 January 2025 Revised: 25 February 2025 Accepted: 10 March 2025

Paper Type: Original Research

Abstract
Aim/Purpose: This study examined the impact of blended learning on science learning achievement and digital skills among Grade 4 students at Ekamai International School, Bangkok. Specifically, it aimed to determine whether there were significant differences in academic performance and digital competency before and after the intervention. By evaluating these outcomes, the study provides insights into the effectiveness of blended learning in enhancing students' understanding of Earth Science and fostering essential digital skills. Additionally, it sought to explore how blended learning influences conceptual understanding, retention, and engagement in elementary science education. The study also examined the role of blended learning in developing students' ability to effectively utilize digital tools for research, communication, and presentations. Furthermore, it aimed to identify best practices for implementing blended learning in elementary classrooms, offering empirical data to inform curricular design and instructional methodologies. By investigating students' perceptions and experiences, this research evaluated the extent to which blended learning impacts motivation, self-directed learning, and overall classroom engagement. The findings of this study contribute to the growing body of knowledge on blended learning in elementary education, providing recommendations for educators and policymakers on optimizing its integration to improve student learning outcomes.

Introduction/Background: Blended learning combines traditional face-to-face instruction with online learning components, creating a flexible and interactive educational experience. This approach has gained attention for its potential to enhance student engagement, achievement, and digital competency by integrating technology into learning. In science education, where critical thinking and digital literacy are essential, blended learning offers opportunities for deeper understanding through multimedia resources, virtual simulations, and interactive activities. While research has demonstrated its benefits in secondary and higher education, its application in elementary education remains underexplored, particularly in improving digital skills and fostering student-centered learning.

Science education plays a crucial role in developing students' problem-solving abilities and inquiry-based learning skills, yet traditional teaching methods often rely on passive instruction that may not fully engage young learners. Blended learning addresses these limitations by providing personalized instruction, self-paced learning, and technology-enhanced activities that support conceptual understanding. Despite the increasing integration of technology in education, there is limited research on how blended learning impacts elementary students' academic performance and digital literacy in Thailand. This study seeks to fill this gap by assessing the effects of blended learning in the Earth Science course for Grade 4 students at Ekamai International School, Bangkok. By examining students' achievement and digital competency before and after the intervention, this research aimed to provide insights into the effectiveness of blended learning in elementary science education and inform best practices for its implementation.

Methodology: This study employed a quasi-experimental one-group pre-test and post-test design to assess the impact of blended learning on science learning achievement and digital skills among 20 Grade 4 students from Ekamai International School, selected through cluster random sampling. The intervention consisted of five Earth Science lessons using a flipped classroom model, spanning 40 instructional hours over ten weeks. Students engaged with online materials before participating in in-class sessions, which focused on hands-on interactive activities. Pre- and post-tests measured changes in science learning achievement and digital skills, using a standardized test and a digital competency assessment. Both instruments were validated for reliability and content accuracy. Paired *t*-tests were conducted to compare pre-test and post-test scores, with a significance level of $p < 0.05$, to determine whether blended learning significantly enhanced students' academic performance and digital literacy. The findings contribute to understanding how blended learning can support elementary science education and digital competency development.

Findings: 1. Science Learning Achievement: The results revealed a statistically significant improvement in students' post-test scores compared to their pre-test scores ($p < .05$). The effect size of the difference using Cohen's d was 2.30, which is considered a large effect size. This indicates that the blended learning approach effectively enhanced their understanding of Earth Science topics.
2. Digital Skills: No statistically significant difference was observed in students' digital skills before and after the intervention ($p > .05$). The effect size of the difference using Cohen's d was 0.41, which is considered a small effect size. This suggests that while the blended learning approach enriched science achievement, its impact on digital skills was not as pronounced within the study's timeframe.

Contribution/Impact on Society: This study contributes to the body of knowledge by providing empirical evidence on the efficacy of blended learning at the elementary level. The findings underscore its potential to improve academic outcomes in science education, while highlighting areas for further development in fostering digital skills. The results offer valuable insights for educators and policymakers who aim to integrate technology into early education, ensuring alignment with 21st century learning demands.

Recommendations: 1. For Practitioners: Implement blended learning models, such as the flipped classroom, in elementary science education to enhance student engagement and achievement. Provide structured guidance to improve digital skills through targeted activities.
2. For Researchers: Explore the long-term effects of blended learning on digital skills and its application across diverse subjects and age groups. Investigate methods to optimize the integration of digital literacy components into lesson plans.

Research Limitations: This study was constrained by its small sample size (20 students), lack of a control group, and short intervention duration 40 hours). The focus on a single subject, Earth Science, and the specific setting of an international school in Bangkok limits the generalizability of findings. Additionally, the study employed only the flipped classroom model, excluding other blended learning approaches that might yield different outcomes.

Future Research: Future studies might consider:
1. Expanding sample sizes and including diverse educational settings to improve generalizability.
2. Extending intervention durations to examine long-term effects on digital skills.
3. Exploring blended learning's impact across multiple subjects and incorporating advanced digital competencies such as coding and multimedia production.
4. Comparing the flipped classroom with other blended learning models to identify the most effective approaches for elementary education.

Keywords: *Blended learning, science learning achievement, digital skills*

Introduction

The rapid advancement of technology has catalyzed significant transformations in education, particularly in the domain of science learning. Blended learning, which integrates traditional classroom instruction with online platforms, has emerged as a promising pedagogical approach to enhance student engagement, academic achievement, and digital literacy. This model, characterized by its flexibility and student-centered design, allows learners to access online and in-person content, fostering autonomy and self-directed learning while improving educational outcomes (Iyer et al., 2024; Smith & Hill, 2019).

Science education plays a crucial role in cultivating critical thinking, problem-solving skills, and scientific literacy, all of which are essential for success in the 21st century. Integrating online programs into blended learning environments adds a new dimension to traditional science education by offering opportunities for personalized learning and leveraging digital tools to deepen students' understanding of scientific concepts. Despite substantial evidence supporting the benefits of blended learning in secondary and higher education, there remains a lack of research exploring its impact on elementary students, particularly in science education.

This study addresses this gap by examining the effects of a flipped classroom model, a specific form of blended learning, on Grade 4 students at Ekamai International School in Bangkok, Thailand. The research aimed to determine whether implementing this model significantly enhances students' science learning achievement and digital skills. The flipped classroom model inverts traditional teaching practices by introducing instructional content outside the classroom, while using in-class time for hands-on, interactive activities. This approach aligns with constructivist principles, encouraging active learning and critical engagement with content.

By synthesizing findings from existing literature and conducting empirical analysis, this study sought to provide evidence-based insights into the effectiveness of blended learning in elementary science education. The results are expected to inform instructional practices, curriculum design, and policy-making, offering practical implications for educators and policymakers striving to optimize learning environments in an increasingly digital age. Furthermore, the study contributes to the growing discourse on educational innovation, emphasizing the potential of blended learning to prepare students for the demands of a technology-driven global society, particularly in the wake of the COVID-19 pandemic, which has accelerated the adoption of online and hybrid learning models.

Research Objectives and Questions

This study aimed to:

1. Evaluate whether the blended learning approach significantly improves science learning achievement in the topic of Earth Science among Grade 4 students.
2. Examine the impact of blended learning on the development of digital skills, including online research, word processing, presentation creation, and Internet safety, in Grade 4 students.
3. Provide evidence-based insights into the potential of blended learning to enhance elementary science education and to equip students with essential digital competencies.
4. Contribute to a broader understanding of blended learning's applicability and effectiveness in elementary education, particularly in science-related subjects.

The objective of this research was to investigate the effects of implementing a blended learning approach on Grade 4 students' science learning achievement and digital skills at Ekamai International School in Bangkok, Thailand.

To achieve these objectives, the study sought to answer the following research questions:

1. Does the implementation of a blended learning approach significantly improve science learning achievement in the topic of Earth Science among Grade 4 students?
2. Is there a statistically significant difference in digital skills development among Grade 4 students before and after implementing blended learning?

Literature Review

The integration of technology into education has brought about a significant shift in teaching and learning practices, particularly in the domain of science education. Blended learning, which merges traditional face-to-face instruction with online components, has gained attention as a transformative pedagogical approach. This section reviews the theoretical framework, empirical findings, and gaps in the literature to provide a foundation for examining the effects of blended learning, specifically the flipped classroom model, on elementary students' science learning achievement and digital skills.

Theoretical Framework

Blended learning is rooted in constructivist theories, particularly those proposed by Piaget and Vygotsky. Piaget's theory of cognitive development emphasizes the active role of learners in constructing knowledge through experiences and interactions with their environment (Piaget, 1971). Similarly, Vygotsky's social constructivism highlights the significance of collaboration and the Zone of Proximal Development, which enables learners to achieve higher levels of understanding with the guidance of more knowledgeable peers or instructors (Vygotsky, 1978). These theories support the design of blended learning environments, where students engage with digital tools and collaborative activities to comprehend scientific concepts better.

Blended Learning in Science Education

Science education is critical in developing problem-solving, critical thinking, and scientific literacy skills. Blended learning, which integrates traditional face-to-face instruction with digital learning experiences, has gained increasing recognition in elementary education. This approach allows students to benefit from personalized learning while maintaining collaborative classroom interactions. Research has indicated that blended learning improves student engagement, comprehension, and achievement in science education (Graham, 2013).

Blended learning in elementary education typically combines synchronous and asynchronous learning methods, utilizing digital platforms, multimedia resources, and interactive activities. By allowing learners to access content online, offline, or in person, blended learning enhances classroom instruction by redesigning the learning environment to provide greater freedom and adaptability to students (Iyer et al., 2024). Research has shown that blended learning approaches, such as the flipped classroom model, improve engagement and comprehension by shifting passive content outside the classroom and utilizing class time for interactive, hands-on activities (Bishop & Verleger, 2013). This method aligns with inquiry-based learning practices, fostering active exploration and real-world problem-solving (Dewey, 1938). Purnama et al. (2023) conducted a systematic literature review highlighting the various models of blended learning, with the flipped classroom emerging as the most common approach. Their study identified that integrating digital tools with traditional instruction enhanced conceptual understanding and student motivation in science education. Furthermore, Stockwell et al. (2015) found that blended learning environments provided opportunities for active learning, improving science education outcomes through digital engagement.

Several studies have examined the effectiveness of blended learning in enhancing student performance in science subjects. Empirical evidence has indicated that blended learning positively impacts academic performance. For instance, Means et al. (2013) found that students in blended learning environments achieved better learning outcomes than those in traditional settings. Similarly, Hwang et al. (2019) demonstrated that elementary students who engaged in blended learning environments exhibited higher academic achievement compared to those in traditional settings. The flexibility and interactive nature of digital tools allowed for more personalized instruction, addressing diverse student learning needs. Seage and Türegün (2020) analyzed the impact of blended learning on science, technology, engineering and mathematics (STEM) education, and found that students who participated in blended science learning outperformed their peers in standardized assessments. These findings underscore the positive correlation between blended learning strategies and improved academic outcomes in science education.

Blended learning not only improves academic performance, but also fosters creativity and student engagement. The use of digital tools in blended learning has been shown to enhance student engagement and motivation, essential factors for effective science education (Garrison & Vaughan, 2008). Miskiah et al. (2020) investigated how blended learning influenced creativity and activeness in elementary students, concluding that the integration of digital and hands-on activities promoted a more engaging and stimulating learning environment. The study emphasized that students in blended classrooms displayed higher levels of curiosity and problem-solving skills. Anthony (2019) further supported these findings, indicating that the combination of traditional teaching best practices with blended learning enhanced student interaction, collaboration, and engagement.

The Flipped Classroom Model

The flipped classroom model is a widely recognized form of blended learning that reverses the traditional teaching structure by delivering instructional content online before class, and utilizing class time for active, collaborative learning (Tucker, 2012). This approach has been shown to improve student engagement, retention, and academic performance, particularly in science education (Lee & Yeung, 2021). By shifting content delivery outside the classroom, students can engage in discussions, problem-solving activities, and hands-on projects during in-person sessions, allowing for a more interactive and student-centered learning experience (Bergmann & Sams, 2012).

The flipped classroom model is aligned with inquiry-based learning, encouraging students to actively explore concepts and apply their knowledge in real-world problem-solving contexts (Dewey, 1938). It also supports differentiated instruction, offering flexibility for students who require additional time to process information or prefer independent learning (Abeysekera & Dawson, 2015). Research has demonstrated that flipped learning enhances critical thinking and problem-solving skills as students engage more deeply with content through active classroom participation (Chen et al., 2014). Say and Yıldırım (2020) further highlighted that this approach fosters collaborative learning, improving student interaction and teamwork in science education.

However, successful implementation of the flipped classroom requires careful planning. Studies have emphasized the importance of teacher facilitation and well-structured digital content to maximize learning outcomes (Lee & Yeung, 2021). Wasriep (2022) examined frameworks for implementing the flipped classroom in primary science education, concluding that teacher training and student readiness are crucial for effective adoption. Similarly, Sharfun and Jung (2024) found that continuous professional development and coaching partnerships significantly influenced preservice teachers' ability to integrate flipped learning strategies effectively.

Despite its benefits, the flipped classroom model presents challenges. Increased preparation time for teachers, the need for student self-discipline, and potential difficulties in adapting younger learners to self-paced digital learning have remained key concerns (Bishop & Verleger, 2013). Without adequate preparation, students may struggle to participate in classroom activities, reducing the effectiveness of the flipped model (O'Flaherty & Phillips, 2015). Additionally, while the model is well-researched in secondary and higher education settings, its application in elementary science education remains underexplored (Wasriep, 2022). Future studies should further investigate its impact on younger students, best practices for implementation, and how to optimize blended learning strategies in primary education.

Digital Skills Development

Digital literacy is increasingly recognized as an essential competency in modern education, equipping students with the skills necessary to navigate both academic and professional environments. Blended learning serves as a powerful approach to fostering digital skills, integrating online research, word processing, and presentation software into students' learning processes (Smith & Hill, 2019). In elementary education, these competencies include information literacy, communication, digital content creation, safety, and problem-solving, all of which are essential for academic success and future careers (Redecker, 2017). Early exposure to digital tools enables students to critically evaluate and responsibly use digital resources (Hobbs, 2010), fostering critical thinking, creativity, and responsible digital citizenship. However, the digital divide remains a significant challenge, as unequal access to technology can limit opportunities for skill development, particularly for students from disadvantaged backgrounds (Livingstone & Helsper, 2007).

The effectiveness of digital literacy instruction depends on structured curriculum design and teacher proficiency in digital technologies. Tondeur et al. (2017) stressed that teachers' pedagogical beliefs strongly influence their use of technology in the classroom, underscoring the need for professional development programs to support effective implementation. Similarly, Erwin and Mohammed (2022) found that structured digital literacy instruction led to increased skill proficiency among students, reinforcing the importance of teacher training and resource allocation. Rakisheva and Witt (2023) emphasized the need for integrating digital competence frameworks into teacher education programs to ensure that educators are well-equipped to facilitate digital learning. Without sufficient teacher support and technological resources, students may not fully develop the necessary digital skills to thrive in an increasingly digital world.

Despite its advantages, digital literacy education in elementary schools faces challenges, including access disparities, insufficient teacher training, and concerns regarding student safety in online environments. Walters et al. (2019) stressed the importance of teaching digital citizenship, ensuring that young learners understand ethical online behavior, data privacy, and cyberbullying prevention. Additionally, Osmani and Tartari (2024) highlighted the impact of digital technology on learning outcomes, showing that while technology can enhance engagement and motivation, its effectiveness depends on how well it is integrated into teaching methodologies. Addressing these challenges requires collaboration between educators, policymakers, and parents to create a balanced and inclusive digital learning environment that prepares students for future technological advancements while ensuring equitable access and responsible use of digital tools.

Research Gaps and Implications

While the benefits of blended learning and the flipped classroom model are well-documented in secondary and higher education, there is limited research on their effectiveness in elementary science education. This gap is significant, as younger students may have different learning needs and require tailored approaches to effectively engage with blended learning environments (Means et al., 2013). Furthermore, the interplay between blended learning and digital skills development at the elementary level remains poorly understood, despite the growing importance of these competencies in a technology-driven society.

Research Methodology

This study employed a quasi-experimental design with a one-group pre-test and post-test approach to evaluate the effects of a blended learning model, specifically the flipped classroom, on Grade 4 students' science learning achievements and digital skills. The quasi-experimental design was chosen to assess changes in the dependent variables before and after the intervention, while maintaining the integrity of the natural classroom setting. The use of a single-group design ensured that all participants were exposed to the same instructional methods, avoiding potential variability between groups. The pre-test and post-test approach with intervention in between was implemented to ensure that the results would represent those from a flipped classroom approach for the topic of Earth Science. No other approaches, such as a control group or any other treatment, were involved. Even if the students were to gain some knowledge or improvement via other methods, such as from extracurricular classes or private tutoring, its effect would have been small, and would not have any statistically significant effects on the other students or the test results. The researcher explained the research process and method to the parents, students, and administrators before the experiment commenced. Both parents and students were informed about the research projects, and parental consent was given. The confidentiality of student personal data, such as identity and academic performance, was protected. Parents and students were assured of fair treatment and transparency throughout the research process.

Population and Sample

The population for this study comprised 118 Grade 4 students enrolled at Ekamai International School in Bangkok, Thailand, during the 2024 academic year. During the study, all Grade 4 students received the same treatment utilizing a blended learning approach to avoid bias and complication. A one-group pre-test and post-test quasi-experiment design was chosen for this study in order to study a single group of participants before and after the intervention. This was considered a quasi-experiment since there was no control group comparison.

The sample group was obtained by cluster random sampling. The 118 students were randomly arranged into mixed-ability groups of 6 class sections, ranging from Section A to G. Each group had approximately 20 representatives. Of the six groups of the total population; one group of 20 students was randomly selected to be used in the experiment and was able to represent the entire population because all six groups had similar characteristics.

Research Instruments

This study utilized three primary instruments; three experts with education backgrounds and extensive teaching experience evaluated the Item-Objective Congruence (IOC) value for each instrument.

1. **Blended Learning Lesson Plans**: Five Earth Science lesson plans, each designed for the flipped classroom model, were developed and implemented over ten weeks. These plans included pre-class online materials (e.g., videos, readings) and in-class collaborative activities (e.g., group discussions, experiments). The content covered Earth's layers, earthquakes and volcanoes, weathering and erosion, rocks and minerals, and fossils, aligning with the Next Generation Science Standards (NGSS).
2. **Science Learning Achievement Test**: A standardized test developed by the researcher measured students' understanding of Earth Science concepts. The test included 30 multiple-choice questions, 14 labeling exercises, and five short-answer questions. The test's content validity was evaluated using Item-Objective Congruence (IOC), with input from subject matter experts (Rovinelli & Hambleton, 1977). The IOC of the Science Learning Achievement test was .97, and the Reliability analysis for the science learning achievement test produced a Kuder-Richardson (KR-20) of .721 (Part 1), .929 (Part 2), and Cronbach's alpha coefficient of .626 (Part 3).
3. **Digital Skills Test**: This test, consisting of 20 multiple-choice questions, assessed students' competencies in word processing, online research, presentation software (e.g., Google Slides), and Internet safety. The test was validated through expert review with an IOC of 1.00, and reliability analysis using Kuder-Richardson (KR-20) of .672, ensuring it was aligned with study objectives (Tavakol & Dennick, 2011).

Data Collection Procedures

The study was conducted over 40 hours during the first quarter of the 2024-2025 academic year, starting on August 13 and ending on October 3, 2024. The students studied science for four hours per week for 10 weeks. Hence, the students were expected to attend the class for 40 hours during the quarter. The procedures included:

1. **Pre-test Administration**: Before the intervention, baseline data on science learning achievement and digital skills were collected using standardized tests. The researcher/teacher at the school administered and monitored this pre-test before the lesson began.
2. **Implementation of Blended Learning:** The flipped classroom model was applied, with students engaging in pre-class online activities and participating in interactive, hands-on activities during class sessions.
3. **Post-test Administration:** Following the intervention, the researcher/teacher administered the same standardized tests to evaluate changes in the dependent variables. The post-test was given as a quarterly examination after the lessons.

Data Analysis

Quantitative data from the pre-tests and post-tests were analyzed using paired sample *t*-tests to determine whether the intervention produced statistically significant changes in science learning achievement and digital skills. Descriptive statistics, including means and standard deviations, were also calculated to provide a clear understanding of the results. Statistical significance was set at $p < 0.05$.

Research Results

The study aimed to evaluate the impact of a blended learning approach, specifically the flipped classroom model, on the science learning achievement and digital skills of Grade 4 students at Ekamai International School in Bangkok, Thailand. Quantitative data were collected and analyzed from pre-tests and post-tests administered before and after the intervention.

Science Learning Achievement

The results showed a significant improvement in science learning achievement among the Grade 4 students after implementing the blended learning approach. The mean score on the post-test was significantly higher than the pre-test, indicating an enhanced understanding of Earth Science concepts. The mean difference in science learning achievement pre-test and post-test was 23.90, where the standard deviation was 10.37. The effect size of the difference using Cohen's d was 2.30, which is considered a large effect size.

Table 1 *Paired Samples Descriptive Statistics for Science Learning Achievement Pre- and Post-Test Scores*

Science Learning Achievements	*n*	Mean	*SD*	*t*	Sig.	Total Score
G4-B Pre-test	2	14.15	4.50	10.30*	.000	283
G4-B Post-test	2	38.05	9.87			761

Note. *$p < .05$.

A paired samples *t*-test was conducted to determine if there was a statistically significant difference between the dependent variable, student science learning achievement pre-test, and post-test. The pre-test and post-test scores of science learning achievement were compared to find statistically significant differences. The results from the paired samples *t*-test were as follows: $t = -10.300$. The pre-test and post-test scores were statistically different, with a significance of $p < .001$. The mean scores from the student science learning achievement post-test were significantly higher than the mean scores from the pre-test. Hence, there was a statistically significant difference in Grade 4 Science student science learning achievement before and after implementing blended learning.

Digital Skills

The digital skills of students were assessed in areas such as word processing, online research, presentation creation, and Internet safety. The post-test results demonstrated a modest improvement in digital skills compared to the pre-test. However, the change was not statistically significant.

Table 2 *Paired Samples Descriptive Statistics for Digital Skills Pre-Test and Post-Test Scores*

	Paired Samples Statistics					
Digital Skills	***n***	**Mean**	***SD***	***t***	**Sig.**	**Total Score**
G4-B Pre-test	20	9.70	3.57	1.83	.083	194
G4-B Post-test	20	10.90	3.75			218

A paired samples *t*-test was conducted to determine if there was a statistically significant difference between the dependent variable, student digital skills pre-test, and post-test. The pre-test and post-test scores of digital skills were compared to find any statistically significant differences. The results from the paired samples *t*-test were as follows: $t = -1.831$. The pre-test and post-test scores were not statistically different, with a significance of $p = .083$. The mean scores from the student digital skills post-test were not significantly different from the mean scores from the pre-test. Hence, there was no statistically significant difference in Grade 4 Science students' digital skills before and after implementing blended learning.

Discussion

The findings from this study highlighted the significant impact of blended learning, specifically the flipped classroom model, on science learning achievement in Grade 4 Earth Science students, but revealed no significant effect on students' digital skills development.

Science Learning Achievement

The results demonstrated a statistically significant increase in student science learning achievement after implementing blended learning, which was aligned with existing research on the benefits of blended learning. It also demonstrated a large effect size with Cohen’s d at 2.30. According to previous studies, blended learning fosters active learning and deeper engagement with the content (Allen & Seaman, 2017; Garrison & Vaughan, 2008). In this study, students' science learning achievement scores improved dramatically from a mean of 14.15 in the pre-test to 38.05 in the post-test. This suggests that students benefited from the flipped classroom's structure, which allowed for more hands-on and interactive activities during class, a key component of constructivist learning theory.

Constructivism, which underpins the flipped classroom approach, emphasizes active student participation in the learning process, where students build knowledge through experiences inside the classroom. The theoretical foundation, supported by Piaget’s and Vygotsky’s work on active learning, reveals how the flipped classroom's interactive activities provide opportunities for learners to construct knowledge rather than passively receive information (Piaget, 1971; Vygotsky, 1978). This study's significant improvement in academic performance reflected this constructivist principle.

Furthermore, the use of digital tools through an online platform (Google Classroom), such as video lectures and interactive simulations, can help promote active learning and collaboration, which are important for deeper understanding and knowledge retention (Dziuban et al., 2004). Students who experience blended learning environments generally perform better than those in traditional face-to-face classroom settings (Seage & Turegun, 2020). This is due to opportunities for personalized learning, where students can review online materials at their own pace, at any place, and at any time through digital platforms (Mean et al., 2013).

Digital Skills

In contrast to science learning achievements, the results for digital skills were less conclusive, with no statistically significant improvement observed in students' digital skills (pre-test mean: 9.70, post-test mean: 10.90). This finding was somewhat surprising given the nature of blended learning, which typically incorporates various digital tools and platforms. However, while students were exposed to digital tools through blended learning, this exposure alone may not have been sufficient to foster significant gains in digital competency. The duration of this study extended to only a quarter of a full semester, which was about 10 weeks or 40 hours. This may have been insufficient for students to gain digital competencies that would make a significant difference in test results.

The researcher believes that one reason why the students’ results did not show significant differences was due to low exposure to digital devices, the digital divide, and accessibility or digital access. The digital divide in elementary education remains a significant barrier to equitable learning opportunities, affecting students’ access to technology, Internet connectivity, and essential digital skills. According to García and Weiss (2020), the COVID-19 pandemic further exposed and deepened existing inequalities in digital access, disproportionately impacting students from low-income households who lacked reliable Internet access and devices for remote learning. This gap is not only about having access to technology, but also about the ability to utilize digital tools effectively, a concept referred to as digital accessibility**.**

Van Deursen and Helsper (2018) highlighted that individuals who can engage meaningfully with digital resources experience greater educational benefits, while those without access fall behind academically.

Furthermore, the digital skills gap in elementary education is exacerbated by the "homework gap," where students without Internet access struggle to complete online assignments, putting them at a long-term disadvantage (Auxier & Anderson, 2020). Research by Hampton et al. (2021) emphasized that broadband connectivity was directly linked to student performance, with those lacking reliable Internet access showing lower academic outcomes. Addressing these disparities requires targeted interventions, including broadband expansion, device accessibility programs, and digital literacy initiatives, to ensure all students can develop the digital skills necessary for future success.

Digital literacy is a complex competency that includes the ability to use digital tools and critical thinking, creativity, and responsible digital citizenship (Howell, 2012). Structured guidance and practice are essential for elementary students to develop these skills. Since the treatment and focus of classroom settings were on science education rather than digital competency, students may have required more exposure to digital tools to show significant differences in the test results. Although this study aimed to determine if there was a relationship between science learning achievement and blended learning, and since blended learning requires the use of digital skills, the secondary objective was related to digital skills. The results suggested that the blended learning model, while effective in improving science learning achievement, may need to be supplemented with specific digital skills training to significantly impact students' digital competencies (Redecker, 2017).

However, the lack of significant improvement in digital skills contrasts with other research that highlights the potential of blended learning to enhance digital competencies (Oliver & Trigwell, 2005). This discrepancy may be due to the specific implementation of the flipped classroom model in this study, which focused more on scientific skills, the nature of science, and content mastery than on the intentional development of digital literacy. It highlights the need for more structured and targeted digital skills instruction within blended learning environments, especially for younger students who may lack foundational digital competencies.

Implications for Practice

The findings of this study highlight the potential of blended learning—specifically the flipped classroom model—to enhance science learning achievement and digital skills in elementary education. By integrating online instructional materials with interactive, hands-on classroom activities, educators can create student-centered learning environments that improve conceptual understanding, engagement, and retention in science. Additionally, the study underscored the importance of developing digital literacy at an early age, as digital tools play an increasing role in education and future careers. Schools should incorporate structured technology-based activities, such as online research, multimedia presentations, and Internet safety lessons, to equip students with essential 21st century skills.

For successful implementation, educators must receive proper training in technology integration and digital pedagogy, ensuring they can design and manage effective blended learning environments. Schools and policymakers should support investments in digital infrastructure, teacher training, and equitable access to technology to prevent disparities in learning opportunities. Additionally, curriculum designers should consider adopting blended learning as a core instructional strategy, integrating it across subjects to enhance both academic performance and independent learning skills. By implementing these strategies, schools can create a more engaging, inclusive, and future-ready education system that fosters both scientific literacy and digital competence among young learners.

Limitations and Future Research

This study was subject to certain limitations, including its small sample size, lack of a control group, and short duration, which may affect the generalizability of its findings. Future research could explore the long-term effects of blended learning on academic achievement and digital skills, and its application across different grade levels and subject areas. Comparative studies examining different blended learning models, such as station rotation or enriched virtual models, could provide deeper insights into their relative effectiveness.

Conclusion

The findings of this study underscore the potential of the flipped classroom model to enhance science learning achievement in elementary education. However, limited improvement in digital skills scores highlights the need for deliberate, targeted strategies to foster digital literacy. By addressing these challenges and leveraging the strengths of blended learning, educators can create engaging, effective learning environments that prepare students for the demands of a technology-driven global society.

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