

Original Article

Effects of Microlearning Based Science Modules on Conceptual Understanding and Self Regulated Learning: A Quasi Experimental Study in Senior Secondary Schools

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Abstract: This study examined the effectiveness of a microlearning-based science module in enhancing students' conceptual understanding and self-regulated learning (SRL). Employing a quasi-experimental non-equivalent control group design, 32 secondary students were equally assigned to experimental (microlearning) and control (conventional instruction) groups. Data were collected through validated conceptual understanding tests, SRL questionnaires, and delayed post-tests to measure retention. Descriptive results showed the experimental group consistently outperformed the control group across all measures, achieving higher mean scores in conceptual understanding ($M = 81.38$, $SD = 6.41$ vs. 72.06 , $SD = 6.87$), SRL ($M = 82.25$ vs. 71.81), and retention ($M = 78.94$ vs. 69.13). Inferential analysis revealed significant differences in overall conceptual understanding ($t = 3.21$, $p = 0.003$) with a large effect size (Cohen's $d = 0.80$), as well as across specific indicators of basic concepts, conceptual application, and scientific reasoning. These findings indicate that microlearning effectively supports deeper conceptual understanding, learner autonomy, and long-term retention by reducing cognitive load and enabling flexible, self-paced learning, positioning it as a promising instructional approach for strengthening science education quality at the secondary level.

Keywords :

Truth microlearning; Secondary science education; Quasi experimental; Science module



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INTRODUCTION

Science is not merely a subject that conveys collections of concepts, laws, and scientific principles, but also serves as a primary vehicle for developing scientific literacy, critical thinking, evidence-based reasoning, and problem-solving skills that are essential

for 21st-century life. Students are expected not only to recall factual information but also to develop deep conceptual understanding, connect scientific ideas, and apply them to complex and novel contexts, including issues related to the environment, health, and technology (Alias & Razak, 2023; Chicué & García-Valcárcel, 2023). Nevertheless, various international reports and empirical studies indicate that these ideal goals of science education have not yet been fully achieved, particularly at the secondary education level. Results from the Programme for International Student Assessment (PISA) consistently show that a large proportion of students remain at a basic level of conceptual understanding and experience difficulties in using scientific knowledge to explain phenomena or solve contextual problems (Alias & Razak, 2023). PISA data indicate that more than 60% of students in many developing countries fail to reach competency levels that require higher-order scientific reasoning. This condition is further supported by numerous studies reporting that the average level of science conceptual mastery among junior and senior high school students ranges only between 40% and 60%, especially for abstract and complex topics such as biological systems, energy and its transformations, ecology, and climate change (Collinson & Tinkler, 2020; De Gagne *et al.*, 2019; Garshasbi *et al.*, 2021)

Based on Cognitive Load Theory, low conceptual understanding in science learning is linked to teacher-centered instruction that presents dense information without effective design to manage cognitive load, leading students to rely on rote memorization, develop misconceptions, and struggle to apply knowledge meaningfully in new contexts. Low conceptual understanding not only affects students' academic achievement but also leads to reduced interest in science learning, persistent misconceptions, and weak ability to relate scientific concepts to real-life situations. Students who lack deep conceptual understanding tend to rely on short-term memorization and struggle to transfer knowledge to new contexts, causing science learning to lose its meaning and relevance (Hesse *et al.*, 2019; Jainuri *et al.*, 2025). One of the major factors contributing to this problem is the dominance of conventional, teacher-centered instructional approaches that emphasize linear content delivery. In everyday classroom practice, science content is often presented in long and dense instructional units, with greater emphasis on syllabus completion and curriculum coverage than on students' depth of understanding. As a result, students are exposed to large amounts of information that must be processed within a limited time frame, without adequate instructional design to manage content complexity.

Human working memory has a limited capacity and is easily overloaded when instruction is not efficiently designed (Kohnke & Moorhouse, 2024; Leong *et al.*, 2020). CLT distinguishes three types of cognitive load: intrinsic load, which is related to the inherent complexity of the material; extraneous load, which arises from ineffective instructional design; and germane load, which is associated with schema construction and learning processes. In science learning, intrinsic cognitive load is typically high due to the abstract and interconnected nature of scientific concepts. If instructional design fails to minimize extraneous cognitive load, students' working memory capacity becomes overwhelmed, thereby hindering conceptual understanding and long-term knowledge construction (McKee & Ntokos, 2022; Monib *et al.*, 2025). Along with the rapid development of educational technology and the demands of 21st-century learning, there is

an increasing need for instructional approaches that are more adaptive, flexible, and learner centered. One approach that has received considerable attention in the international literature is microlearning. Microlearning is defined as a learning strategy that delivers content in small, focused, and short-duration units designed to achieve specific learning objectives (Mostrady *et al.*, 2024; Moulin *et al.*, 2026). This approach emphasizes content segmentation, focus on a single key concept at a time, and the use of digital media that enables flexible access to learning. From the perspective of CLT, microlearning offers advantages by reducing extraneous cognitive load through concise and well-structured information presentation, allowing learners to process information more effectively. By breaking down complex material into meaningful segments, microlearning enables students to build conceptual understanding gradually and systematically (Marlina *et al.*, 2025; Moulin *et al.*, 2026). This approach is particularly relevant to science education, where conceptual understanding often requires the integration of multiple ideas and scientific representations.

Research has shown that microlearning can enhance key components of SRL, including learning planning, comprehension monitoring, and self-reflection (Marlina *et al.*, 2023; Nowak *et al.*, 2023; Pinto *et al.*, 2025). In science education, the ability to revisit and independently reflect on concepts is essential for fostering deep and sustainable understanding. The urgency of developing microlearning-based science modules has become increasingly evident in the context of digital transformation and post-COVID-19 education. The pandemic has accelerated the adoption of digital technologies in education and encouraged the implementation of hybrid and online learning models. However, research indicates that the use of technology without sound instructional design may reduce learning quality and increase learning fragmentation (Qamar *et al.*, 2025; Rof *et al.*, 2024). Therefore, technology-enhanced learning designs must be not only innovative but also grounded in robust learning theories and empirical evidence. Despite the growing body of international literature highlighting the potential of microlearning, empirical studies that simultaneously integrate microlearning design, conceptual understanding, and self-regulated learning within the context of secondary science education remain limited. Most microlearning research has been conducted in higher education or professional training settings, while studies focusing on junior and senior high school contexts characterized by distinct cognitive development stages and learning needs are still scarce (Cate *et al.*, 2023; Senadheera *et al.*, 2024; Wakam *et al.*, 2022). Furthermore, many studies examine the impact of microlearning on a single learning outcome, such as motivation or retention, without comprehensively investigating its effects on both conceptual understanding and SRL.

This study is grounded in Cognitive Load Theory as the instructional design foundation and Self-Regulated Learning theory as the framework for fostering learner autonomy. By integrating these two theoretical perspectives, the developed microlearning modules are expected to deliver science learning that is effective, efficient, and learner centered. Theoretically, this study is expected to contribute to the literature on microlearning in science education by providing empirical evidence of its role in improving conceptual understanding and SRL among secondary school students.

Practically, the findings are expected to serve as a reference for teachers, instructional designers, and policymakers in designing and implementing microlearning-based science instruction aligned with the demands of 21st-century education. This study aims to examine the differences in students' conceptual understanding of science between those who learn through microlearning modules and those who receive conventional instruction at the junior secondary school level.

Persistent gaps in students' conceptual understanding of science highlight the need for instructional designs that are both cognitively efficient and supportive of learner autonomy. Guided by principles from cognitive load theory and self-regulated learning theory, microlearning science modules offer a promising approach to segment complex content while fostering planning, monitoring, and reflection in learning. However, empirical evidence examining their combined impact on conceptual understanding and self-regulated learning among junior and senior secondary students especially within contextualized science education settings such as environmental topics relevant to local regions remains limited. Therefore, this quasi-experimental study evaluates the implementation of contextualized microlearning-based science modules to determine whether they improve students' conceptual understanding and self-regulated learning compared with conventional instruction, providing practical and theoretical contributions to secondary science education.

THEORETICAL SUPPORT

Conceptual Understanding in Junior Secondary Science through Microlearning

Conceptual understanding in science refers to students' ability to meaningfully organize scientific knowledge, explain phenomena, establish relationships among concepts, and apply scientific ideas to new and real-world contexts (Wang *et al.*, 2020; Zhang & West, 2020). However, international large-scale assessments and empirical studies consistently indicate that many secondary school students demonstrate superficial understanding of scientific concepts and struggle with knowledge transfer and reasoning (Alias & Razak, 2023; Hamdani, 2025). One major theoretical explanation for this phenomenon is provided by Cognitive Load Theory (CLT). Cognitive Load Theory (CLT) posits that learning effectiveness is constrained by the limited capacity of working memory, particularly when learners are exposed to complex and abstract information, as is typical in science education. Instructional designs that present dense content in extended lessons often impose excessive extraneous cognitive load, thereby hindering schema construction and long-term conceptual understanding (Adams *et al.*, 2022; Adler & Akad, 2024). Consequently, ineffective management of cognitive load becomes a critical barrier to meaningful science learning at the secondary level. In response to these challenges, microlearning emerges as an instructional approach theoretically aligned with CLT principles. Microlearning structures learning content into small, focused, and goal-oriented units, each targeting a specific concept or skill (Almulla, 2023). From a cognitive perspective, this segmented design reduces extraneous cognitive load and allows learners to process information incrementally, facilitating deeper conceptual integration (Efgivia *et al.*, 2021). In science learning, where conceptual understanding often requires the gradual

integration of abstract ideas, microlearning provides a theoretically sound mechanism for managing intrinsic cognitive load and supporting conceptual development.

Beyond cognitive considerations, effective science learning also depends on students' ability to regulate their own learning processes. Self-Regulated Learning (SRL) theory emphasizes learners' active role in planning, monitoring, and evaluating their learning activities (Torres *et al.*, 2024; Wong *et al.*, 2021). Empirical evidence suggests that students with higher levels of SRL demonstrate stronger conceptual understanding, greater learning persistence, and improved academic outcomes in science (Alfatemi *et al.*, 2024). Nevertheless, secondary school students often exhibit low SRL, largely due to instructional practices that limit autonomy and reflection (Marlina *et al.*, 2023; Torres *et al.*, 2024).

Microlearning is theoretically positioned to support SRL development by providing learners with greater control over learning pace, content sequencing, and repetition. Short and modular learning units allow students to plan their learning more effectively, monitor their understanding in real time, and revisit challenging concepts as needed (Wong *et al.*, 2021). Thus, microlearning not only addresses cognitive limitations but also creates learning conditions conducive to the development of SRL skills, which are essential for sustained conceptual understanding in science. Integrating Cognitive Load Theory and Self-Regulated Learning theory, this study conceptualizes microlearning as an instructional intervention that simultaneously reduces cognitive overload and enhances learner autonomy. Within this framework, microlearning-based science modules are hypothesized to improve students' conceptual understanding by optimizing information processing and to strengthen self-regulated learning by promoting active, reflective, and independent learning behaviors. Accordingly, this theoretical framework underpins the present study's investigation into differences in conceptual understanding between students learning through microlearning modules and those experiencing conventional instruction at the junior secondary school level.

METHOD

A quasi-experimental method was employed to examine students' levels of conceptual understanding and self-regulated learning before and after the implementation of a science learning intervention in authentic classroom settings, where full randomization of participants was not feasible. The study adopted a pretest–posttest non-equivalent control group design, which allows for objective and measurable comparisons of learning outcomes between the experimental and control groups (Paramasivan *et al.*, 2024). Sample selection was conducted using purposive sampling, whereby participants were deliberately chosen based on predefined criteria aligned with the research objectives. The sample consisted of two intact classes at the same educational level one assigned as the experimental group and the other as the control group drawn from partner schools that had agreed and were prepared to implement the intervention. The selection criteria included: (1) schools located within the designated intervention area, (2) relatively comparable academic and social characteristics, (3) teachers' willingness to participate in professional mentoring and to implement the prescribed instructional materials, and (4) students'

minimum access to the learning devices required for the intervention. The assignment of classes to the experimental and control conditions was conducted without individual randomization. However, to reduce potential research bias, the equivalence of the two groups was carefully considered by examining their initial ability levels based on pretest results prior to the intervention. Figure 1 presented the stages of participant selection involved in this study.

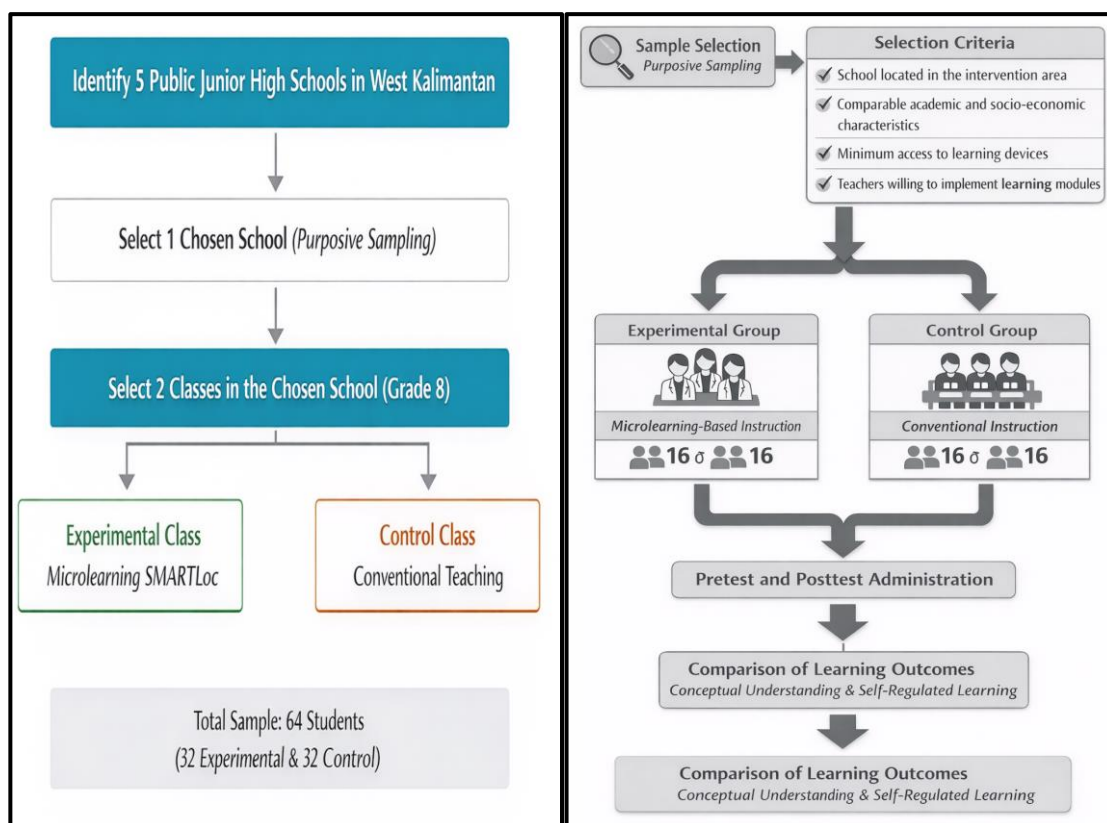


Figure 1. Research Participants

Sample selection was conducted using a multistage sampling technique. In the first stage, the researchers identified five (5) public junior secondary schools in West Kalimantan that shared relatively similar characteristics, including the implementation of the Merdeka Curriculum, the availability of basic ICT facilities (internet access and digital devices), and balanced class sizes. In the second stage, one (1) school was purposively selected as the main research site based on infrastructure readiness, institutional support, and teachers' willingness to fully participate in the study. In the third stage, two classes at the same grade level (Grade 8) were selected from the chosen school. These classes demonstrated relatively equivalent academic ability based on students' previous semester report scores. One class was assigned as the experimental group receiving microlearning-based instruction, while the other served as the control group receiving conventional instruction. From each class, 32 students were selected using stratified random sampling based on gender, consisting of 16 male and 16 female students. Thus, the total sample size of the study comprised 64 students.

This study employed three main types of instruments: a science conceptual understanding test, a self-regulated learning (SRL) questionnaire, and supporting instructional instruments (learning analytics logs and observation sheets). All instruments were developed and adapted from previously validated instruments and were tailored to the context of science learning at the secondary education level. This study employed three main types of instruments: a science conceptual understanding test, a self-regulated learning (SRL) questionnaire, and supporting instructional instruments (learning analytics logs and observation sheets) (Table 1). All instruments were developed and adapted from previously validated instruments and were tailored to the context of science learning at the secondary education level.

Table 1. Instrument of Research

Instrument	Type of Instrument	Measured Indicators	Number of Items	Source of Development
Science Conceptual Understanding Test	Objective multiple-choice test (4 options)	Explaining concepts, interpreting phenomena, connecting concepts, applying concepts, identifying misconceptions	25 items	(Addido <i>et al.</i> , 2022)
Self-Regulated Learning (SRL) Questionnaire	5-point Likert scale questionnaire	Planning, monitoring, cognitive strategies, motivational regulation, self-reflection	24 statements	(So <i>et al.</i> , 2020; Zhang & West, 2020)
Microlearning3/8/2026 11:42:00 PM Observation Sheet	Structured observation instrument	Design alignment, student engagement, interaction, UDL implementation, time management	15 indicators	
Student Response Questionnaire	5-point Likert scale questionnaire	Ease of use, clarity of materials, engagement, learning autonomy, satisfaction	20 statements	(Wicaksono & Korom, 2023)

Table 1 presents four research instruments designed to comprehensively capture cognitive, behavioral, and affective dimensions of the study. The Science Conceptual Understanding Test consists of 25 multiple-choice items (four options) adapted from Addido *et al.* (2022), measuring students' ability to explain concepts, interpret phenomena, connect related ideas, apply concepts in problem-solving contexts, and identify misconceptions. This instrument focuses on assessing higher-order conceptual comprehension rather than mere factual recall. In addition, the Self-Regulated Learning (SRL) Questionnaire, adapted from So *et al.* (2020) and Zhang and West (2020), comprises 24 statements rated on a five-point Likert scale. It evaluates key components of self-regulation, including planning, monitoring, cognitive strategy use, motivational regulation, and self-reflection.

To complement these instruments, a Microlearning Observation Sheet containing 15 structured indicators was employed to document the quality of instructional implementation. The observation focused on design alignment, student engagement, interaction patterns, Universal Design for Learning (UDL) implementation, and time

management to ensure fidelity of the intervention. Furthermore, the Student Response Questionnaire, consisting of 20 Likert-scale statements adapted from [Wicaksono and Korom \(2023\)](#), was used to capture students' perceptions of ease of use, clarity of materials, engagement, learning autonomy, and overall satisfaction. Together, these instruments enable triangulation of data by integrating learning outcomes, self-regulatory processes, instructional quality, and learner perceptions.

RESULT AND DISCUSSION

This study measures student learning outcomes, particularly those related to Science Conceptual Understanding and SLR. Table 2 displays a descriptive analysis.

Table 2. Descriptive Statistic Of Research

Variable	Class	N	Min	Max	Mean	SD
Science Conceptual Understanding Test	Experiment (Microlearning)	16	68	92	81.38	6.41
Science Conceptual Understanding Test	Control (Conventional)	16	60	85	72.06	6.87
Self-Regulated Learning (SRL) Questionnaire	Experiment (Microlearning)	16	70	90	82.25	5.98
Science Conceptual Understanding Test	Control (Conventional)	16	62	82	71.81	6.35

The results of the descriptive analysis indicate that the experimental group, which learned using the microlearning modules, achieved a higher mean score in science conceptual understanding ($M = 81.38$) compared to the control group, which obtained a mean score of 72.06. The mean difference of 9.32 points suggests a practically meaningful difference in students' conceptual achievement. The score range in the experimental group (68–92) shows that most students reached a moderate to high level of conceptual understanding, particularly on indicators related to explaining concepts in their own words and connecting scientific concepts to real-life contexts. In contrast, the control group was predominantly characterized by basic-level conceptual understanding, with students tending to perform well on factual questions but showing less consistency on items requiring application and scientific reasoning.

The standard deviations of the two groups were relatively comparable (SD experimental = 6.41; SD control = 6.87), indicating a relatively homogeneous distribution of students' abilities across groups. This similarity in score variability suggests that the observed difference in mean scores can be reasonably attributed to the instructional treatment rather than to disparities in students' initial ability levels. For the self-regulated learning variable, the experimental class showed a higher average score of 82.25 compared to the control class with an average of 71.81. This difference reflects that microlearning provides greater control over learning to students. Specifically, the most prominent improvements in the experimental class were in the indicators of learning planning (determining the time and sequence of learning), monitoring understanding (realizing parts of the material that have not been understood), and self-reflection after completing the module. In contrast, students in the control class showed a tendency to rely on teacher direction and had lower scores on the monitoring and reflection indicators. This

strengthens the finding that the modular and flexible microlearning design supports the development of student self-regulation. Table 3 shows the results of the inferential science conceptual understanding test.

Table 3. Inferential Test Results

Test Indicator	Statistics	t/ Z test	P value	Effect Size	Interpretation
Science Conceptual Understanding	Independent Samples t-test	t = 3.21	0.003	Cohen's d = 0.80	Big Impact
Basic Concept Indicator	t-test	t = 2.67	0.012	d = 0.57	Medium Impact
Application Concept Indicator	U-Mann Whitney	Z = 2.45	0.014	r = 0.43	Medium Impact
Scientific Reasoning	t-test	t = 3.05	0.005	d = 0.76	Big Impact

The inferential analysis revealed a significant difference between students participating in microlearning-based learning and students in conventional classes in their overall understanding of science concepts ($t = 3.21$; $p = 0.003$). The effect size (Cohen's $d = 0.80$) indicated that the difference was large, indicating a strong practical impact of microlearning on student learning outcomes. At the indicator level, significant differences were also found in the basic concepts and scientific reasoning indicators, with effect sizes in the medium to large category. Meanwhile, for the concept application indicator, the Mann–Whitney test showed a significant difference ($Z = -2.45$; $p = 0.014$) with a medium effect size ($r = 0.43$), indicating that the microlearning approach was more effective in helping students apply science concepts to real-world contexts.

Descriptively, students in the microlearning class consistently achieved higher average scores than those in the conventional class on all measured indicators. These findings indicate that the integration of local wisdom-based microlearning content and an inclusive approach can improve students' conceptual understanding more effectively than conventional learning approaches. Table 4 shows a summary of student learning outcomes for each indicator.

Table 4. Inferential Test Results

Indicator	Group	Mean / Median	SD / IQR	Achievement Category	Comparison
Basic Concept	Microlearning	82.4	6.8	High	Superior
	Conventional	74.1	7.2	Medium	
Application Concept	Microlearning	79.6 (Median)	8.0 (IQR)	High	Superior
	Conventional	71.3 (Median)	9.1 (IQR)	Medium	
Scientific Reasoning	Microlearning	84.2	6.1	High	Superior
	Conventional	73.5	7.5	Medium	
Total	Microlearning	82.1	6.5	High	Superior
	Conventional	73.0	7.3	Medium	

In basic concept mastery, the microlearning group achieved a high level of achievement ($M = 82.4$), while the conventional group remained at a medium level ($M = 74.1$). A similar pattern was found for concept application, where the microlearning group

reached a high category (Median = 79.6) compared to the medium category in the conventional group (Median = 71.3). The strongest difference appeared in scientific reasoning, with microlearning students achieving high performance ($M = 84.2$), whereas conventional students showed only medium achievement ($M = 73.5$). Overall, the total scores confirm this trend: the microlearning group attained a high level of achievement ($M = 82.1$), while the conventional group remained in the medium category ($M = 73.0$). These findings indicate that microlearning-based instruction is superior to conventional instruction in enhancing students' science learning outcomes across conceptual understanding, application, and reasoning. The analysis of the basic concept indicator revealed that students in the microlearning group significantly outperformed those in the conventional group ($t = 2.67, p = 0.012, d = 0.67$).

Although the effect size falls within the medium-to-large range, its educational significance should not be underestimated, as mastery of basic concepts constitutes the foundation for higher-order cognitive processes in science learning. From a theoretical standpoint, this finding can be explained through Cognitive Load Theory (CLT), which emphasizes the importance of managing learners' working memory capacity during instruction (Zhang & West, 2020). Microlearning reduces extraneous cognitive load by presenting information in concise units, thereby enabling learners to focus their cognitive resources on understanding core concepts rather than processing excessive or redundant information. This instructional efficiency is particularly beneficial in science education, where abstract concepts often impose high intrinsic cognitive load (Hamdani & Marlina, 2025; Senadheera et al., 2024). Moreover, microlearning facilitates repeated exposure and retrieval practice, which are critical mechanisms for strengthening conceptual memory (Hamdani et al., 2025; Qamar et al., 2025; Wang et al., 2020). By engaging with short learning units, students can revisit key concepts multiple times, reinforcing their understanding and reducing misconceptions. This aligns with recent empirical findings showing that segmented digital instruction enhances conceptual clarity and reduces error rates in science learning (Collinson & Tinkler, 2020; Marlina, 2024).

The conceptual application indicator, analyzed using the Mann–Whitney U test due to non-normal data distribution, also showed a statistically significant difference in favor of the microlearning group ($Z = -2.45, p = 0.014, r = 0.43$). The medium effect size suggests that microlearning has a meaningful impact on students' ability to apply scientific concepts to problem-solving contexts. Conceptual application requires learners to transfer abstract knowledge to new situations, a process that is often challenging in traditional instructional settings. Conventional teaching methods tend to emphasize content coverage and procedural instruction, which may limit opportunities for learners to actively apply concepts (Efgivia et al., 2021; Nowak et al., 2023). In contrast, microlearning environments often incorporate interactive elements, contextual examples, and formative assessments that encourage active engagement and application (Mostrady et al., 2024; Torres et al., 2024). International studies have demonstrated that microlearning supports knowledge transfer by embedding learning activities within authentic contexts and providing immediate feedback (Wong et al., 2021; Zhang & West, 2020). Similarly, national research indicates that microlearning modules designed around local contexts and

real-world problems significantly enhance students' ability to apply scientific concepts (Addido *et al.*, 2022; Dessí *et al.*, 2022). These findings align closely with the results of the present study, suggesting that microlearning fosters deeper learning by bridging the gap between theory and practice.

One of the most notable findings of this study is the significant improvement in scientific reasoning among students in the microlearning group ($t = 3.05, p = 0.005, d = 0.76$). Scientific reasoning involves complex cognitive processes such as analyzing evidence, drawing inferences, and evaluating explanations. The large effect size observed indicates that microlearning is particularly effective in supporting higher-order thinking skills. This result can be interpreted through the lens of constructivist learning theory, which posits that learners actively construct knowledge through meaningful engagement with content (Alfatemi *et al.*, 2024; Antonietti *et al.*, 2023). Microlearning environments often encourage learner autonomy, self-paced exploration, and reflective thinking, all of which are conducive to the development of scientific reasoning. By allowing students to control the pace and sequence of learning, microlearning supports individualized cognitive processing and promotes deeper engagement with complex ideas (Ariffiando *et al.*, 2023; Hendriksen *et al.*, 2024).

Recent international studies have reported similar findings, showing that technology-enhanced microlearning environments improve students' analytical reasoning and argumentation skills in science (Addido *et al.*, 2022; Akinrinade & Du, 2025). In Indonesia, research on digital and inquiry-based microlearning approaches also indicates significant gains in scientific reasoning and critical thinking (Husamah *et al.*, 2022). The present study adds to this growing body of evidence by providing experimental data that confirms the effectiveness of microlearning in fostering higher-order cognitive outcomes.

Experimental and quasi-experimental studies across various educational contexts report that students engaged in microlearning-based instruction show significant improvements in conceptual understanding and long-term retention compared to those in conventional learning environments (Chan & Lee, 2023; Gu *et al.*, 2024; Korthals Altes *et al.*, 2024). STEM education contexts, microlearning has been reported to improve student learning outcomes by approximately 15–35%, particularly for topics requiring deep conceptual understanding and visualization (Alfi *et al.*, 2024; Almulla, 2023). Moreover, microlearning has been shown to enhance learner engagement and attention. The delivery of content in short and visually rich formats helps students maintain focus and actively process information (Korthals Altes *et al.*, 2024; Wang *et al.*, 2020). In science learning, high levels of cognitive engagement are a critical prerequisite for meaningful conceptual understanding, as students must actively connect new concepts with their prior knowledge.

In addition to challenges related to conceptual understanding, science education at the secondary level also faces the issue of low self-regulated learning (SRL) among students. SRL refers to an individual's ability to consciously and systematically plan, monitor, and evaluate their own learning processes (Bortes & Giota, 2024; Senadheera *et al.*, 2024). Research indicates that students with strong SRL skills tend to exhibit higher learning motivation, more effective learning strategies, and better academic achievement,

including in science learning (Alfatemi *et al.*, 2024; Bajorath, 2024). However, many studies show that most junior and senior high school students still demonstrate low levels of SRL and remain highly dependent on teacher guidance. In science learning, students often struggle to plan learning strategies, monitor their conceptual understanding, and reflect on errors or (Hasibuan *et al.*, 2023; Mandikonza, 2022). This condition is exacerbated by instructional practices that provide limited opportunities for independent and reflective learning.

Microlearning inherently promotes learner autonomy by enabling students to access content independently, manage their learning time, and monitor their own progress through frequent assessments and feedback (Dessí *et al.*, 2022). Empirical research consistently demonstrates a positive relationship between digital learning environments and SRL development (Agarwal & Bain, 2019; Alfi *et al.*, 2024; Hamdani & Marlina, 2025). Microlearning, in particular, has been shown to support key SRL components such as goal setting, self-monitoring, and self-evaluation (Hasibuan *et al.*, 2023). These processes likely contributed to the superior performance of the microlearning group in the present study, especially in tasks requiring conceptual application and scientific reasoning. From a practical perspective, fostering SRL is increasingly recognized as a critical goal of 21st-century education, as learners are expected to adapt to rapidly changing knowledge and technological landscapes (Hasibuan *et al.*, 2023; Marlina, 2024). The findings of this study suggest that integrating microlearning into science instruction may serve as an effective strategy for promoting both cognitive and metacognitive development.

The findings of this study have important implications for educational practice and policy. First, they support the integration of microlearning into science curricula as a complementary approach to conventional instruction. Teachers can leverage microlearning modules to reinforce key concepts, provide enrichment activities, and support differentiated instruction. Second, educational institutions and policymakers should consider investing in professional development programs that equip teachers with the skills necessary to design and implement effective microlearning content. This includes training in instructional design, digital pedagogy, and formative assessment strategies.

Finally, at the policy level, the adoption of microlearning aligns with broader educational reform initiatives aimed at promoting digital literacy, learner autonomy, and lifelong learning (Bajorath, 2024; Golke & Wittwer, 2024). By incorporating microlearning into formal education systems, policymakers can support more flexible, inclusive, and effective learning environments. Despite its contributions, this study has several limitations that should be acknowledged. The relatively small sample size limits the generalizability of the findings, and future studies should involve larger and more diverse populations. Additionally, future research should directly measure self-regulated learning and other affective variables to better understand the mechanisms underlying microlearning's effectiveness. Longitudinal are also needed to examine the long-term retention and transfer of knowledge gained through microlearning. Furthermore, future research could explore the integration of adaptive technologies and learning analytics to enhance personalization and further improve learning outcomes.

CONCLUSION

Students who participated in microlearning consistently achieved higher mean scores across all measured variables with statistically significant differences and medium-to-large effect sizes, indicating that microlearning not only improves immediate learning outcomes but also supports deeper conceptual processing and longer-term retention, reinforcing Cognitive Load Theory and constructivist principles through its segmented, focused design that helps students manage cognitive demands, actively construct knowledge, and engage in higher-order thinking, while observed improvements in self-regulated learning further demonstrate that microlearning fosters learner autonomy, metacognitive awareness, and reflective habits essential for 21st-century education. Practically, these findings position microlearning as particularly suitable for junior secondary students requiring structured yet flexible support, offering educators an effective complement to classroom instruction for differentiated learning and key concept reinforcement, while at the policy level supporting integration into science curricula and digital initiatives within frameworks such as Kurikulum Merdeka to promote meaningful, inclusive, and sustainable practices. In conclusion, this study establishes microlearning as a pedagogically robust approach that bridges cognitive and metacognitive development by reducing cognitive load while promoting learner autonomy, contributing to the growing evidence base for microlearning in secondary science education and suggesting future research directions exploring longitudinal effects across diverse subject areas and integration with emerging technologies including artificial intelligence and adaptive learning systems to further personalize and optimize student learning experiences.

REFERENCES

- Adams, T., Koster, B., & Brok, P. den. (2022). Patterns in student teachers' learning processes and outcomes of classroom management during their internship. *Teaching and Teacher Education*, *120*, 103891. <https://doi.org/10.1016/j.tate.2022.103891>
- Addido, J., Burrows, A., & Slater, T. (2022). The Effect of the Conceptual Change Model on Conceptual Understanding of Electrostatics. *Education Sciences*, *12*(10), 696. <https://doi.org/10.3390/educsci12100696>
- Adler, I., & Akad, I. (2024). New roles for science teachers: A cultural-historical activity theory intervention to support education for health, wellbeing, and citizenship. *Teaching and Teacher Education*, *145*, 104635. <https://doi.org/10.1016/j.tate.2024.104635>
- Agarwal, P. K., & Bain, P. M. (2019). *Powerful Teaching: Unleash the Science of Learning*. John Wiley & Sons.
- Akinrinade, O., & Du, C. (2025). Skin cancer detection using deep machine learning techniques. *Intelligence-Based Medicine*, *11*, 100191. <https://doi.org/10.1016/j.ibmed.2024.100191>
- Alfatemi, A., Jamal, S. A. L., Paykari, N., Rahouti, M., & Chehri, A. (2024). Multi-Label Classification with Deep Learning and Manual Data Collection for Identifying Similar Bird Species. *Procedia Computer Science*, *28th International Conference on Knowledge Based and Intelligent Information and Engineering Systems (KES 2024)*, *246*, 558–565. <https://doi.org/10.1016/j.procs.2024.09.461>
- Alfi, B. R., Paidi, P., & Pratama, A. T. (2024). Validating instrument to assess science literacy and independent learning skills in high school. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *10*(3), Article 3. <https://doi.org/10.22219/jpbi.v10i3.34770>
- Alias, N. F., & Razak, R. A. (2023). Exploring The Pedagogical Aspects Of Microlearning In Educational Settings: A Systematic Literature Review. *Malaysian Journal of Learning and Instruction*, *20*(2), 267–294. <https://doi.org/10.32890/mjli2023.20.2.3>
- Almulla, M. A. (2023). Constructivism learning theory: A paradigm for students' critical thinking, creativity, and problem solving to affect academic performance in higher education. *Cogent Education*, *10*(1), 2172929. <https://doi.org/10.1080/2331186X.2023.2172929>

- Antonietti, C., Schmitz, M.-L., Consoli, T., Cattaneo, A., Gonon, P., & Petko, D. (2023). "Development and validation of the ICAP Technology Scale to measure how teachers integrate technology into learning activities." *Computers & Education*, 192, 104648. <https://doi.org/10.1016/j.compedu.2022.104648>
- Ariffiando, N. F., Susanti, A., Azaria, F. Y., & Darmansyah, A. (2023). Pengembangan Model Pembelajaran Problem Based Learning Berbasis Budaya Lokal Masyarakat Pesisir Bengkulu untuk Meningkatkan Sikap Sosial Siswa Sekolah Dasar. *Jurnal PGSD: Jurnal Ilmiah Pendidikan Guru Sekolah Dasar*, 16(1), Article 1. <https://doi.org/10.33369/pgsd.16.1.1-14>
- Bajorath, J. (2024). Potential inconsistencies or artifacts in deriving and interpreting deep learning models and key criteria for scientifically sound applications in the life sciences. *Artificial Intelligence in the Life Sciences*, 5, 100093. <https://doi.org/10.1016/j.ails.2023.100093>
- Bortes, C., & Giota, J. (2024). Beyond academics: Links from teaching practices in Swedish schools to students' achievements and mental health complaints. *Learning and Instruction*, 92, 101937. <https://doi.org/10.1016/j.learninstruc.2024.101937>
- Cate, D. T., Dikken, J., Ettema, R. G. A., Schoonhoven, L., & Schuurmans, M. J. (2023). Development of a microlearning intervention regarding nursing nutritional care for older adults: A multi-methods study. *Nurse Education Today*, 120, 105623. <https://doi.org/10.1016/j.nedt.2022.105623>
- Chan, C. K. Y., & Lee, K. K. W. (2023). The AI generation gap: Are Gen Z students more interested in adopting generative AI such as ChatGPT in teaching and learning than their Gen X and millennial generation teachers? *Smart Learning Environments*, 10(1), 60. <https://doi.org/10.1186/s40561-023-00269-3>
- Chicué, B. V., & García-Valcárcel, A. (2023). Microlearning for the Development of Teachers' Digital Competence Related to Feedback and Decision Making. *Education Sciences*, 13. <https://doi.org/10.3390/educsci13070722>
- Collinson, C., & Tinkler, S. (2020). Innovative On-Demand Microlearning Versus Traditional Instruction. *Journal of Obstetric, Gynecologic & Neonatal Nursing, SI: Proceedings of the AWHONN 2020 Convention*, 49(6, Supplement), S74. <https://doi.org/10.1016/j.jogn.2020.09.128>
- Dessí, D., Osborne, F., Reforgiato Recupero, D., Buscaldi, D., & Motta, E. (2022). SCICERO: A deep learning and NLP approach for generating scientific knowledge graphs in the computer science domain. *Knowledge-Based Systems*, 258, 109945. <https://doi.org/10.1016/j.knosys.2022.109945>
- Efgivia, M. G., Rinanda, R. Y. A., Suriyani, Hidayat, A., Maulana, I., & Budiarmo, A. (2021). *Analysis of Constructivism Learning Theory*. 208–212. <https://doi.org/10.2991/assehr.k.211020.032>
- Gagne, J.C., Park, H. K., Hall, K., Woodward, A., Yamane, S., & Kim, S. S. (2019). Microlearning in Health Professions Education: Scoping Review. *JMIR Medical Education*, 5(2), e13997. <https://doi.org/10.2196/13997>
- Garshasbi, S., Yecies, B., & Shen, J. (2021). Microlearning and computer-supported collaborative learning: An agenda towards a comprehensive online learning system. *STEM Education*, 1, 225. <https://doi.org/10.3934/steme.2021016>
- Golke, S., & Wittwer, J. (2024). Informative narratives increase students' situational interest in science topics. *Learning and Instruction*, 93, 101973. <https://doi.org/10.1016/j.learninstruc.2024.101973>
- Gu, C., Jin, F., & Li, Y. (2024). The mediating role of psychological capital in the relationship between foreign language anxiety and learning burnout among college students with different language environments. *System*, 126, 103499. <https://doi.org/10.1016/j.system.2024.103499>
- Hamdani, H. (2025). Penerapan model ECIRR untuk mereduksi jumlah mahasiswa yang miskonsepsi tentang usaha dan energi. *Jurnal Pendidikan Informatika Dan Sains*, 14(1), 130–138. <https://journal.upgripnk.ac.id/index.php/saintek/article/view/8244>
- Hamdani, H., & Marlina, R. (2025). Development of School Center of Excellence (SCE) program to realize literacy and numeracy-friendly school standards. *Research and Development in Education (RaDeN)*, 5(1), 754–766. <https://ejournal.umm.ac.id/index.php/raden/article/view/40895>
- Hamdani, H., Saefi, M., Marlina, R., Sudrajat, A. K., & Pamungkas, R. (2025). What do professional science teachers need today? A learning model integrating reflection and collaboration principles. *Indonesian Journal of Science and Mathematics Education*, 8(2), 214–229. <https://ejournal.radenintan.ac.id/index.php/IJSME/article/view/22480>
- Hasibuan, H. Y., Syarifudin, E., Suherman, & Santosa, C. A. H. F. (2023). Ethnoscience as the Policy Implementation of Kurikulum Merdeka in Science Learning: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, 9(8), Article 8. <https://doi.org/10.29303/jppipa.v9i8.4500>
- Hendriksen, N., Logtenberg, A., Westbroek, H., & Janssen, F. (2024). Exploring teachers' agency in inclusive education: Secondary education teachers navigating their projects in responding to the diversity in students' sociocultural backgrounds. *Teaching and Teacher Education*, 149, 104731. <https://doi.org/10.1016/j.tate.2024.104731>

- Hesse, A., Ospina, P., Wieland, M., Yepes, F. A. L., Nguyen, B., & Heuwieser, W. (2019). *Short communication: Microlearning courses are effective at increasing the feelings of confidence and accuracy in the work of dairy personnel. Journal of Dairy Science, 102*(10), 9505–9511. <https://doi.org/10.3168/jds.2018-15927>
- Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. (2022). The development and validation of environmental literacy instrument based on spirituality for prospective science teachers. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(12), em2206. <https://doi.org/10.29333/ejmste/12732>
- Jainuri, M., Kamid, K., Syaiful, S., & Huda, N. (2025). Microlearning Effectiveness in Higher Education: A Systematic Review and Meta-Analysis of Student Retention and Learning Outcomes. *MATHEMA: Jurnal Pendidikan Matematika, 7*, 630–642. <https://doi.org/10.33365/jm.v7i2.517>
- Kohnke, L., & Moorhouse, B. L. (2024). An exploration of microlearning as continuous professional development for English language teachers: Initial findings and insights. *Open Learning: The Journal of Open, Distance and e-Learning, 0*(0), 1–17. <https://doi.org/10.1080/02680513.2024.2362649>
- Korthals Altes, T., Willemse, M., Goei, S. L., & Ehren, M. (2024). Higher education teachers' understandings of and challenges for inclusion and inclusive learning environments: A systematic literature review. *Educational Research Review, 43*, 100605. <https://doi.org/10.1016/j.edurev.2024.100605>
- Leong, K., Sung, A., Au, D., & Blanchard, C. (2020). A review of the trend of microlearning. *Journal of Work-Applied Management, ahead-of-print*. <https://doi.org/10.1108/JWAM-10-2020-0044>
- Mandikonza, C. (2022). Collaborative learning experiences and development of capabilities among first-year pre-service teachers learning Cell Biology concepts. *Social Sciences & Humanities Open, 5*(1), 100254. <https://doi.org/10.1016/j.ssaho.2022.100254>
- Marlina, R. (2024). Goal-setting and problem-solving in the tech-enhanced classroom a teaching and learning reboot: By Pete Atherton, (New York, NY: Routledge, 2023), 216 pp., £36.99 (paperback), £120.00 (hardback), £33.29 (eBook). ISBN 9781032117614. *Interactive Learning Environments, 32*(9), 5866–5869. <https://doi.org/10.1080/10494820.2023.2211629>
- Marlina, R., Suwono, H., Ibrohim, I., Yuenyong, C., Hamdani, H., & Pamungkas, R. (2025). CRTP: Learning model for integrating STEM competencies in pre-service biology teachers. *Journal of Education and Learning (EduLearn), 19*(3), 1466–1473. <http://edulearn.intelektual.org/index.php/EduLearn/article/view/21818>
- Marlina, R., Suwono, H., Yuenyong, C., Ibrohim, I., & Hamdani, H. (2023). Reflection Practice in Microteaching: Evidence from Prospective Science Teachers. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah, 8*(1), Article 1. <https://doi.org/10.24042/tadris.v8i1.15846>
- Marlina, R., Suwono, H., Yuenyong, C., Ibrohim, I., Mahanal, S., Saefi, M., & Hamdani, H. (2023). Technological Pedagogical Content Knowledge (TPACK) for Preservice Biology Teachers: Two Insights More Promising. *Participatory Educational Research, 10*(6), 245–265. <https://doi.org/10.17275/per.23.99.10.6>
- McKee, C., & Ntokos, K. (2022). Online microlearning and student engagement in computer games higher education. *Research in Learning Technology, 30*. <https://doi.org/10.25304/rlt.v30.2680>
- Monib, W. K., Qazi, A., & Apong, R. A. (2025). Microlearning beyond boundaries: A systematic review and a novel framework for improving learning outcomes. *Heliyon, 11*(2), e41413. <https://doi.org/10.1016/j.heliyon.2024.e41413>
- Mostrady, A., Sanchez-Lopez, E., & Gonzalez-Sanchez, A. (2024). Microlearning and its Effectiveness in Modern Education: A Mini Review. *Acta Pedagogica Asiana, 4*, 33–42. <https://doi.org/10.53623/apga.v4i1.496>
- Moulin, T., Lellouche, N., Gandjbakhch, E., & Laredo, M. (2026). Daily Quiz-Based Microlearning Program to Support Electrocardiogram Interpretation Training for Medical Students: A Feasibility Study. *CJC Open, 8*(1), 43–50. <https://doi.org/10.1016/j.cjco.2025.09.009>
- Nowak, G., Speed, O., & Vuk, J. (2023). Microlearning activities improve student comprehension of difficult concepts and performance in a biochemistry course. *Currents in Pharmacy Teaching and Learning, 15*(1), 69–78. <https://doi.org/10.1016/j.cptl.2023.02.010>
- Paramasivan, S., Bhan, A., Rodrigues, R., & Menon, U. (2024). Trials Methodology Research: What is it and why should India invest in it? *The Lancet Regional Health - Southeast Asia, 22*, 100360. <https://doi.org/10.1016/j.lansea.2024.100360>
- Pinto, R., Perez, A. L., Gonçalves, G., Lampón, J. F., & Pérez-Moure, H. (2025). A Proposed Educational Framework for Professional Upskilling in Smart Manufacturing: On-Demand Microlearning Units. *Procedia Computer Science, 6th International Conference on Industry 4.0 and Smart Manufacturing, 253*, 2039–2048. <https://doi.org/10.1016/j.procs.2025.01.265>

- Qamar, F., Benfor, B., Oh, A., Ford, C., Watson, J., Drake, M., Ibarra, C., Benavides, B. A., Peden, E. K., & Rahimi, M. (2025). Video-based microlearning improves vascular surgery resident proficiency in end-to-side anastomosis. *Journal of Vascular Surgery Cases, Innovations and Techniques*, 11(6), 101986. <https://doi.org/10.1016/j.jvscit.2025.101986>
- Rof, A., Bikfalvi, A., & Marques, P. (2024). Exploring learner satisfaction and the effectiveness of microlearning in higher education. *The Internet and Higher Education*, 62, 100952. <https://doi.org/10.1016/j.iheduc.2024.100952>
- Senadheera, V., Muthukumarana, C., Ediriweera, D., & Rupasinghe, T. (2024). Impact of microlearning on academic performance of students in higher education: A systematic review and meta-analysis. *Journal of Multidisciplinary & Translational Research*, 9, 10–25. <https://doi.org/10.4038/jmtr.v9i1.2>
- So, H.-J., Lee, H., & Roh, S.-Z. (2020). *Examining the Design of Microlearning for Korean Adult Learners*. <https://doi.org/10.35542/osf.io/dmu4c>
- Torres, A. C., Duarte, M., Pinto, D., & Mouraz, A. (2024). Self-regulated learning in secondary school: Students' self-feedback in a peer observation programme. *Studies in Educational Evaluation*, 83, 101407. <https://doi.org/10.1016/j.stueduc.2024.101407>
- Wakam, G. K., Palmon, I., Kulick, A. A., Lark, M., Sonnenday, C. J., & Waits, S. A. (2022). Adapting to the Times: Combining Microlearning Videos and Twitter to Teach Surgical Technique. *Journal of Surgical Education*, 79(4), 850–854. <https://doi.org/10.1016/j.jsurg.2022.02.001>
- Wang, C., Bakhet, M., Roberts, D., Gnani, S., & El-Osta, A. (2020). The efficacy of microlearning in improving self-care capability: A systematic review of the literature. *Public Health*, 186, 286–296. <https://doi.org/10.1016/j.puhe.2020.07.007>
- Wicaksono, A. G. C., & Korom, E. (2023). Attitudes towards science in higher education: Validation of questionnaire among science teacher candidates and engineering students in Indonesia. *Heliyon*, 9(9), e20023. <https://doi.org/10.1016/j.heliyon.2023.e20023>
- Wong, J., Baars, M., de Koning, B. B., & Paas, F. (2021). Examining the use of prompts to facilitate self-regulated learning in Massive Open Online Courses. *Computers in Human Behavior*, 115, 106596. <https://doi.org/10.1016/j.chb.2020.106596>
- Zhang, J., & West, R. E. (2020). Designing Microlearning Instruction for Professional Development Through a Competency Based Approach. *TechTrends*, 64(2), 310–318. <https://doi.org/10.1007/s11528-019-00449-4>