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The Influence of the iSCan Mobile Seamless Learning Model on the Enhancement of Students' Metacognitive Skills in Physics Learning

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Abstract: Metacognitive skills play a critical role in helping students plan, monitor, and evaluate their learning processes, especially in complex disciplines such as physics. However, traditional instruction still tends to provide limited opportunities for students to regulate their own cognition. This study aims to examine the effectiveness of the iSCan–Mobile Seamless Learning (MSL) model in improving students' metacognitive regulation skills in physics learning. The model integrates continuous metacognitive scaffolding through digital mobile platforms and in-class activities, enabling learners to engage in self-regulated interactions across multiple learning environments. A quasi-experimental design was employed with 102 students randomly assigned to an experimental group using the iSCan–MSL model and a control group receiving conventional instruction. Data on metacognitive skills specifically indicators of planning, monitoring, and evaluation, were collected using a validated rubric-based assessment and analysed with MANOVA and effect size measures. The results indicate significant improvements in students' metacognitive regulation in the experimental group compared to the control group ($p < .05$), with moderate-to-strong effect sizes across the three indicators. These findings demonstrate that the iSCan–MSL model facilitates more active and conscious cognitive engagement, confirming the theoretical expectation that seamless learning environments enrich self-regulatory behaviours. The scientific novelty of this research lies in its integration of the iSCan learning cycle with metacognitive prompts and continuous digital support, which has not been widely implemented in physics contexts. In practice, the study offers a promising instructional alternative for educators to enhance metacognition through technology-supported pedagogies. Recommendations for future research include expanding the participant pool and incorporating real-time analytics to deepen the understanding of metacognitive processes during learning.

Keywords: iSCan Model, Mobile Seamless Learning, Metacognitive Skills, Physics Education, Fluid Mechanics

Introduction

In the digital era, independent and reflective learning skills are increasingly important for students to adapt to the demands of flexible learning (Galimova et al., 2025). Metacognition—defined as the awareness and regulation of one's own thinking processes—has been widely recognised as a key component of effective learning (Stanton et al., 2021). Research indicates that improved metacognitive skills are positively associated with enhanced learning outcomes at both secondary and tertiary levels (Willison et al., 2024). Other studies further confirm that the explicit implementation of metacognitive strategies is positively correlated with learning achievement and educational efficiency (Ishak et al., 2025), making the integration of metacognition into science learning highly relevant for preparing students to navigate the complexities of the 21st century.

In the context of digital learning, many mobile learning practices still prioritise content delivery over reflection. Galimova et al. (2025) Reported that mobile learning tasks implemented without metacognitive scaffolding led to only moderate improvements in higher-order thinking skills and did not significantly enhance students' self-regulation. Recent literature also indicates that the use of metacognitive strategies in e-learning is significantly associated with academic engagement and performance (Willison et al., 2024). However, their effectiveness depends greatly on the integration of monitoring, scaffolding, feedback, and structured reflection activities (Stanton et al., 2021).

In line with these developments, recent studies using learning analytics have shown that process data such as activity logs enable teachers to provide adaptive feedback that strengthens students' self-regulation and metacognition (Pacheco et al., 2025; Villa-Torrano et al., 2025). This approach is highly relevant for designing seamless mobile learning models that incorporate rich monitoring, reflection, and evaluation activities, such as the iSCan–MSL model. Therefore, developing and testing learning models that integrate metacognitive components with seamless mobile learning features is crucial to supporting reflective, continuous, and contextual physics learning.

Research Problem

The global use of mobile learning continues to increase. Yet, studies show that many implementations still lack reflective activities, making them less effective in enhancing self-regulated learning (SRL) and metacognition. Villa-Torrano et al. (2025) Highlighted the need for digital interventions that integrate metacognitive scaffolding to address students' weak self-regulation. Therefore, the development of the iSCan-MSL model is highly relevant to current educational challenges. Enhancing high school students' metacognition directly contributes to improving scientific literacy, problem-solving abilities, and readiness for both future careers and further studies. This, in turn, strengthens the quality of STEM education, which is increasingly essential in modern society.

Theoretically, this research enriches the literature on the integration of metacognition, learning analytics, and mobile seamless learning. Pacheco et al. (2025) Emphasised the importance of exploring the relationship between data processing and metacognitive indicators—a dimension rarely examined in physics education. While extensive literature exists on metacognition and mobile learning, studies examining the explicit influence of metacognitive scaffolding on high school physics learning remain limited. Previous research has largely been descriptive and has not utilised learning analytics as part of metacognitive evaluation (Stanton et al., 2021; Villa-Torrano et al., 2025). This study introduces novelty by testing the iSCan-MSL model, which integrates three key components—monitoring, reflection, and evaluation—and employs process data to analyse students' metacognitive development more comprehensively. Thus, this research helps uncover the mechanisms through which metacognition-based, seamless mobile interventions influence physics learning outcomes.

Research Focus

The focus of this research is to evaluate the effectiveness of implementing the iSCan Mobile Seamless Learning (iSCan-MSL) model, which is designed to facilitate self-monitoring, structured reflection, and evaluation supported by adaptive feedback. The study examines explicitly: (1) improvements in students' metacognitive skills; (2) the use of process data from the mobile platform as indicators of metacognitive activity; and (3) changes in physics learning outcomes in the experimental group compared to the control group. The scientific focus of this study lies in integrating the concepts of metacognition, mobile seamless learning, and learning analytics as recommended by previous research (Pacheco et al., 2025; Villa-Torrano et al., 2025).

In this study, three indicators of metacognitive regulation, planning, monitoring, and evaluation, are emphasised. These indicators were selected because they represent the core processes through which learners regulate their cognition over time: planning helps learners to set goals, organize resources, and prepare appropriate strategies before engaging in a task; monitoring involves continuously checking one's understanding or progress during the learning process; and evaluation (or reflection) enables learners to assess outcomes, judge the effectiveness of strategies, and adjust future learning actions accordingly. These three components have been consistently identified in metacognition literature as fundamental aspects of self-regulated learning (Noushad, 2009; Schraw, 1998). The theoretical foundation for the planning-monitoring-evaluation approach comes from the seminal model proposed by John H. Flavell. In his work "Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry," Flavell (1979) defined metacognition as "cognition about cognition," comprising both metacognitive knowledge (e.g., knowledge about strategies, tasks, and one's abilities) and metacognitive regulation the active orchestration of cognitive processes, particularly through planning, monitoring, and evaluating one's own thinking and learning processes.

Moreover, instruments widely used to measure metacognitive awareness, such as the Metacognitive Awareness Inventory (MAI), operationalise metacognitive regulation through subcomponents that map closely onto planning, monitoring, and evaluation (e.g., planning/goal setting, information-management strategies, comprehension monitoring, self-evaluation). Therefore, by adopting planning–monitoring–evaluation as central indicators, this study aligns with well-established theoretical and empirical frameworks in metacognition research, thereby ensuring conceptual clarity and robust grounding for investigating how a mobile seamless-learning intervention (iSCan–MSL) can support self-regulated, reflective physics learning.

Research Aim and Research Questions

The purpose of this study was to evaluate the effect of implementing the iSCan Mobile Seamless Learning (iSCan-MSL) model on students' metacognitive skills in high school physics. The specific objectives were to: (1) measure the improvement in students' metacognitive skills after participating in learning using the iSCan-MSL model; (2) analyze the relationship between process log indicators (learning analytics) and metacognitive development; (3) compare physics learning outcomes between the experimental and control groups; and (4) identify technical challenges in implementing mobile seamless learning that may influence the effectiveness of metacognitive scaffolding (Ugwu et al., 2025). The following research questions guided this study:

- Does the iSCan-MSL model significantly improve students' metacognitive skills compared to conventional learning models?
- Which components of the iSCan-MSL model (monitoring, reflection, evaluation) contribute most to enhancing students' metacognition?
- What is the relationship between process data indicators on the mobile platform and changes in students' metacognitive scores?
- Does the implementation of the iSCan-MSL model have a significant effect on physics learning outcomes?
- What technical barriers emerge during the implementation of the iSCan-MSL model, and how do they affect learning effectiveness?

Literature Review

Current literature supports the premise that explicit metacognitive scaffolding, combined with learning analytics–based feedback, has strong potential to improve both metacognitive skills and learning outcomes. However, the heterogeneity of methods, measurement approaches, and learning contexts requires rigorous research designs, including validation of process data indicators, clear control of intervention components, and adequate sample sizes. Therefore, testing the iSCan-MSL model in high school physics learning addresses an essential gap in the literature, particularly in validating LA indicators as reflections of metacognitive development and examining the relative contribution of each component (monitoring, reflection, evaluation).

Theoretical Framework: Metacognition, Self-Regulated Learning, and Seamless Mobile Learning

Metacognition began to attract scholarly interest in the mid-1960s through studies conducted by Hart, Underwood, and Arbuckle and Cuddy (Arbuckle & Cuddy, 1969; Hart, 1965; Underwood, 1966). During the late 1970s, the concept was expanded to encompass individuals' ability to plan, act with awareness, and direct themselves toward specific goals when engaged in cognitive tasks. Flavell (1979) Further clarified that metacognition includes a person's understanding of their own thinking processes, the results of those processes, and the factors that influence them, including the characteristics of information used for learning. Metacognition is generally understood to consist of two major components: knowledge of cognitive processes and the ability to regulate and monitor those processes (Gagne, 1985; Hamilton, 1994). Thus, metacognition refers to the awareness and regulation of one's own thinking, including planning, monitoring, and evaluating cognitive strategies during problem-solving. Contemporary educational literature positions metacognition as a key driver of independent learning and higher-order thinking, contributing directly to academic achievement at both secondary and tertiary levels.

Meta-analytic evidence and systematic reviews show a consistent positive correlation between metacognitive skills and learning outcomes, particularly in problem-solving domains such as mathematics and science (Xie et al., 2024). Self-regulated learning (SRL) represents an overlapping and complementary construct. SRL emphasises students' capacity to manage learning goals, strategies, time, and motivation, whereas metacognition provides the framework for monitoring and evaluating these processes. Interventions that incorporate explicit metacognitive prompts, reflective scaffolding, and structured feedback have been shown to enhance both SRL and metacognitive indicators (Baars et al., 2022). Seamless learning and mobile seamless learning (MSL) describe paradigms that promote continuity of learning experiences across formal and informal settings through mobile technologies that bridge temporal and spatial boundaries. In seamless learning, students are not required to remain in a constant state of learning (Wong & Looi, 2011). Rather, the paradigm enables them to learn anytime and anywhere when relevant stimuli or contexts arise.

Seamless learning aligns with the notions of "anywhere learning" and "augmented learning," which refer to technology-enhanced environments that allow students to flexibly access materials, notifications, or learning guidance (Virtanen et al., 2018). The MSL model has the potential to support reflective practice when designed with explicit elements for monitoring, reflection, and evaluation. However, in many implementations, mobile learning continues to focus primarily on content delivery, offering insufficient metacognitive scaffolding. Studies on MSL development and implementation show promising effects on engagement and learning continuity, yet its overall effectiveness depends heavily on instructional design and teacher-supported feedback (Ulfa, 2014). Learning analytics (LA) offers new opportunities to monitor students' learning processes through activity logs and other forms of process data. When integrated as a reflective tool, such as through the visualisation of learning traces, feedback derived from LA usage patterns can enhance metacognitive awareness and support teachers in providing adaptive interventions. Recent evidence on AI-based LA and real-time feedback suggests positive effects on SRL and certain components of metacognition, although empirical findings vary by the design and context of the intervention (J. Chen, 2024; Durall & Gros, 2014).

Trends in mobile and seamless learning research

Over the past five years (2020–2025), research has increasingly moved toward integrating learning analytics (LA) with self-regulated learning (SRL) and metacognition. Systematic studies have examined the use of LA as a metacognitive tool, including activity visualisations, reflective dashboards, and adaptive recommendations. The findings indicate improvements in students' metacognitive awareness and several aspects of self-regulation, particularly when students receive training in interpreting and using these dashboards effectively (Pacheco et al., 2025). Additionally, recent studies have focused on mobile applications and metacognitive prompts. Numerous investigations of mobile applications that incorporate prompts for planning, checklists, and reflection have reported improvements in learners' self-monitoring and strategy use, especially in language learning and introductory STEM subjects. However, evidence supporting the generalisation of these findings to high school physics remains limited and requires further empirical validation (Baars et al., 2022). Current research has also moved toward seamless learning to support contextual continuity. Experiments in Mobile Seamless Learning (MSL) conducted across various countries, including several in the Asian region, underline the importance of learning continuity, gamification, and integration between formal and informal learning spaces. Aligned with these trends, this study implemented a learning model that emphasises the continuity and interconnectedness of learning experiences across time and space (Ningsih et al., 2022).

This approach enables more effective and flexible learning environments by supporting continuous learning processes unconstrained by location or scheduling. MSL activities can begin in the classroom and continue at home as assignments, or arise spontaneously from online discussions, thereby deepening students' understanding of physics concepts (Wong et al., 2015). Much of the current literature still focuses on model development and pilot testing (R&D), while large-scale quasi-experimental evaluations remain relatively rare (Qolbi et al., 2024; Ulfa, 2014). Furthermore, contextualization within science and physics education shows that metacognitive strategies such as self-explanation and reflective prompts effectively improve conceptual understanding and problem-solving skills when combined with active instruction. However, the application of mobile seamless learning specifically in high school physics remains limited (Osman et al., 2025). Geographically, research across both developed and developing countries shows consistent evidence that metacognitive approaches are effective when taught explicitly. Differences generally arise from disparities in infrastructure (e.g., mobile device access, LMS availability, teacher readiness) and variations in learning culture that influence technology adoption.

The methodological approach used and the conflicting conclusions

Empirical studies assessing the effects of metacognitive interventions and learning analytics (LA) on SRL and metacognition include randomised controlled trials (RCTs), quasi-experimental studies, correlational research (using both self-report and performance-based measures), and implementation and R&D studies. Variability in findings often arises from differences in how metacognition is defined and measured. Some studies rely on self-report questionnaires, which are susceptible to bias. In contrast, others employ process data indicators (e.g., clicks, time-on-task, revision patterns) that provide more objective signals of cognitive processes but still require validation as proxies for metacognition. These differences in instrumentation complicate cross-study comparisons (Mahande et al., 2021). Further inconsistencies stem from variation in intervention design. Interventions that merely add mobile features without structured training or metacognitive scaffolding tend to yield minimal effects on self-regulation.

In contrast, interventions that integrate explicit prompts, reflection rubrics, and adaptive LA-based feedback consistently demonstrate significant improvements (Baars et al., 2022). Another important source of variation is the subject-matter context. Evidence from mathematics and language learning does not always align with findings from physics education, as physics often requires complex conceptual representations and advanced modelling skills that necessitate carefully tailored metacognitive designs (Xie et al., 2024).

Empirical outcomes: effect sizes and statistical evidence

A summary of quantitative findings from recent studies reveals a general pattern: structured metacognitive interventions (prompts + monitoring + feedback) produce small-to-moderate effects on metacognition scores and learning outcomes when measured using pre–post designs and non-equivalent control groups. Several learning analytics–based studies have also reported statistically significant increases in SRL (e.g., $p < 0.05$), with effect sizes ranging from 0.3 to 0.6. However, meta-analyses and systematic reviews highlight substantial heterogeneity across studies and emphasise the need for larger sample sizes and more valid process-based measures (Xie et al., 2024). Examples of synthesized findings from several representative studies include the following: (1) Study A (quasi-experimental; $n \approx 180$) reported a mean increase in metacognitive scores of $\Delta = 0.45$ SD ($p < 0.01$) following a mobile-learning intervention incorporating metacognitive prompts (Juniantari et al., 2025); (2) Study B (RCT; blended LA feedback; $n \approx 120$) demonstrated improvements in SRL and final learning outcomes with an effect size of approximately $d \approx 0.35$ ($p < 0.05$) (J. Chen, 2024); (3) Study C (MSL piloting in high schools; $n \approx 150$) showed increased engagement and conceptual gains in selected physics topics, although measurable effects on metacognition remained weak when structured reflection components were absent (Wulandari, 2022).

Research gaps and further research needs

Validation of process data indicators as proxies for metacognition in high school physics contexts remains limited. Although learning analytics (LA) is widely promoted, the validity of specific log indicators as measures of monitoring or reflection is still largely untested (Durall & Gros, 2014). Few studies comparing scaffolding components have examined the relative contributions of monitoring, reflection, and evaluation within the MSL model; thus, comparative experimental designs are needed to identify which components are most effective (Baars et al., 2022). The scale and duration of many existing studies are also limited, with most implementations being short-term pilots; consequently, long-term evidence, particularly regarding the sustainability and transferability of metacognitive improvements to other learning contexts, remains scarce (Ulfa, 2014). Additionally, cultural and technical factors in developing countries, including infrastructure constraints, teacher readiness, and access to mobile technologies, influence the implementation of MSL. Therefore, more cross-country studies are required to improve the generalizability of findings (Qolbi et al., 2024).

Materials and Methods

This study employed a quantitative, quasi-experimental design to analyse the effect of implementing the iSCan–Mobile Seamless Learning (MSL) model on students' scientific thinking skills. The research used a control-group pretest–posttest design involving two comparison groups: an experimental group and a control group. In the experimental group, the learning process was conducted using the iSCan–MSL model, whereas the control group received physics instruction through a conventional approach without integration of the model. Learning activities in the experimental group were structured into four continuous phases that reflect the principles of seamless learning: the informal phase, formal phase 1, formal phase 2, and the integrative phase between the two. All research activities centred on physics practicums focusing on static and dynamic fluids, which served as the contextual foundation for implementing this innovative learning strategy.

Table 1

Research Design

Group	Pretest	Treatment	Postest
Y_1	O_1	X	O_2
Y_2	O_3	--	O_4

Source: prepared by researchers based on research design (Creswell & Creswell, 2018)

Y1: Indicates the experimental group that received instruction using the iSCan–Mobile Seamless Learning (MSL) model.

Y2: Indicates the control group that participated in physics learning without the iSCan–MSL model, following conventional teaching methods.

O1: Refers to the pretest administered to the experimental group before the learning process.

O2: Refers to the posttest administered to the experimental group after the learning process was completed.

O3: Indicates the pretest administered to the control group before the learning process.

O4: Indicates the posttest administered to the control group after the learning process.

X: Represents the special treatment in the form of the iSCan–MSL model applied to the experimental group.

--: Indicates that the control group did not receive the iSCan–MSL treatment.

Sample and Participants

The subjects of this study were students from Muhammadiyah 10 GKB Gresik Senior High School. The study population consisted of all eleventh-grade students, with an average age of 17 years, divided into two classes totalling 102 students. All members of the population were included in the sampling process using simple random sampling. The two classes were combined and then randomly assigned into two treatment groups to ensure a more balanced distribution of student characteristics. The experimental group consisted of 51 students who participated in physics learning using the iSCan–Mobile Seamless Learning (MSL) model, while the control group, also comprising 51 students, engaged in physics learning using a conventional approach without the model.

Instrument and Procedure

The data collection technique for this study employed a questionnaire to measure students' metacognitive skills. The metacognitive skill indicators consisted of eight aspects: (1) Knowledge of cognition (declarative, procedural, and conditional knowledge), which refers to students' awareness of what they know (declarative), how to perform certain tasks (procedural), and when or why to use specific strategies (conditional) (Gregory & Sperling, 1994); (2) Planning, which includes setting learning or experimental goals, outlining procedural steps, selecting variables or tools, and estimating time (Gregory & Sperling, 1994); (3) Process monitoring, which involves continuously tracking progress in completing tasks—checking assumptions, examining data development, and reviewing understanding throughout the activity (Stanton et al., 2021); (4) Evaluation and reflection, which refers to assessing outcomes in relation to goals or hypotheses, evaluating the reliability of evidence, and drawing lessons for improvement (Gregory & Sperling, 1994).

(5) Regulation strategies/control, which is the ability to adjust or modify strategies when monitoring indicates difficulties (e.g., changing measurement techniques or revising procedures) (Amin et al., 2022); (6) Representation and cognitive modeling, which includes creating and interpreting graphs, tables, diagrams, and conceptual models that depict physical phenomena, and evaluating the appropriateness of these models with respect to the data (Dulger & Ogan-Bekiroglu, 2025); (7) Resource management and help-seeking, which involves managing learning resources (notes, tools, literature) and seeking structured assistance when necessary (Osman et al., 2025); (8) Confidence and affective regulation, which encompasses students' confidence in their cognitive abilities and their strategies for managing emotions during learning (Gregory & Sperling, 1994).

Table 2

Metacognitive Skills Indicator Matrix

No.	Indicators	Operational sub-indicators	Activity
1	Knowledge of cognition	○ Knowing what is being learned (declarative). ○ Knowing how to perform experimental procedures (procedural). ○ Knowing when/why certain strategies are used (conditional).	○ Explain the concepts of hydrostatic pressure, Pascal's law, and Bernoulli's. ○ Determine procedures for measuring fluid pressure. ○ Explain the rationale for using the ρgh formula under certain conditions..

2	Planning	○ Establish learning/experimental objectives. ○ Develop work steps and select research tools and variables. ○ Estimate completion time.	○ Write the objectives of the Pascal and Archimedes' laws experiment. ○ Design steps for observing pressure changes. ○ Estimate the time required to collect pressure data.
3	Process monitoring	○ Monitor progress and understanding during learning. ○ Check the suitability of assumptions and preliminary data. ○ Identify difficulties during the experimental process.	○ Rechecking pressure measurement results at different depths. ○ Observing fluid stability in a U-tube. ○ Highlighting parts of a concept that are not yet understood (e.g., viscosity).
4	Evaluation / reflection	○ Assess the experimental results against the objectives/hypothesis. ○ Evaluate the reliability of the data and procedures. ○ Draw lessons for improvement in the next experiment.	○ Compare lab results with Bernoulli's law. ○ Identify sources of fluid measurement errors. ○ Write a reflection on learning outcomes in a student journal.
5	Strategic regulation / control	○ Changing strategies when monitoring reveals problems. ○ Improving data collection procedures or techniques. ○ Restructuring approaches to achieve more accurate results.	○ Change the pressure measurement technique to a digital manometer. ○ Correct the instrument position to ensure stable results. ○ Change the sequence of experimental steps if results are inconsistent.
6	Cognitive representation and modeling	○ Create graphs, tables, or models of physics concepts. ○ Interpret the results of the representations to draw conclusions. ○ Assess the model's suitability to experimental data..	○ Create a pressure-depth relationship graph. ○ Interpret a fluid flow diagram in a constricted pipe. ○ Create a model of the relationship between buoyancy force and the volume of an immersed object.
7	Resource management and assistance	○ Manage time, tools, and materials efficiently. ○ Utilize additional learning resources (literature, digital media). ○ Seek help from teachers or peers in a targeted manner.	○ Use measuring instruments efficiently and in turn. ○ Access Pascal's Law simulation videos via MSL. ○ Discuss experimental difficulties with the teacher.
8	Emotional /cognitive regulation	○ Demonstrate self-confidence in completing tasks. ○ Control emotions when facing difficulties. ○ Demonstrate perseverance and a positive attitude toward the learning process.	○ Remain calm when experimental results do not match theory. ○ Patiently attempt to repeat measurements. ○ Demonstrate optimism in completing lab reports.

Source: prepared by researchers based on metacognitive skills indicators

Table 3

Metacognitive Skills Assessment Rubric

No.	Indikator	Skor	
1	Knowledge of cognition	4	Demonstrates a full understanding of physics concepts, procedures, and rationale for using strategies (appropriately within the context of fluid law).
		3	Understands basic concepts and procedures but is inconsistent in explaining the rationale for their use.
		2	Understands some concepts/procedures but is incorrect in applying the strategies.
		1	Does not understand concepts/procedures and has difficulty explaining the rationale for their use.
2	Planning	4	Systematically designs objectives, experimental steps, and selects tools, while realistically estimating time.
		3	Prepares a reasonably well-defined plan but lacks detail in steps or timing.
		2	Prepares a basic plan but lacks clarity on variables or tools.
		1	Does not demonstrate a clear plan.
3	Process monitoring	4	Actively monitors progress, checks data consistency, and identifies errors during experiments.
		3	Monitors some processes, but is not consistent in checking.
		2	Monitors infrequently and relies on teacher direction.
		1	Does not demonstrate monitoring of the learning process or experiments.
4	Evaluation / reflection	4	Critically evaluate results, compare them with theory, and write meaningful reflections.
		3	Conduct general evaluations, but the reflections are still descriptive.
		2	Only assess final results without comparing them with theory.
		1	Do not evaluate or reflect on learning outcomes.
5	Strategic regulation / control	4	Able to adjust strategies or improve procedures independently when encountering obstacles.
		3	Changes strategies after being guided or directed by the teacher.
		2	Recognizes errors but does not change strategies.
		1	Inability to adjust strategies even when results are not satisfactory.
6	Cognitive representation and modeling	4	Creates graphs, tables, or physics models correctly and interprets results logically.
		3	Creates representations that are somewhat accurate but have limited interpretation.
		2	Creates representations that are imprecise and fail to interpret data.
		1	Does not create or copy models without understanding.
7	Resource management and assistance	4	Manages time and tools efficiently and actively seeks scientific assistance when needed.
		3	Manages learning resources fairly well but not efficiently.
		2	Often requires assistance without attempting to be independent.
		1	Inability to manage resources or tends to be passive.
8	Emotional /cognitive regulation	4	Demonstrates high self-confidence, patience, and optimism during experiments.
		3	Demonstrates self-confidence but is easily influenced by unfavorable results.
		2	Often anxious or hesitant about tasks.
		1	Demonstrates a negative attitude or gives up easily.

Source: prepared by researchers based on metacognitive skills indicators

Table 4

Metacognitive Skills Questionnaire Instrument

Indikator	No.	Pertanyaan
Knowledge of cognition	1	I understand the basic concepts of fluid statics and dynamics before the lab begins.
	2	I understand the steps involved in fluid experiments, such as measuring pressure or viscosity.
	3	I understand the rationale for using one experimental procedure over another.
	4	I can explain how Archimedes' or Bernoulli's principles are applied in everyday life.
Planning	5	Before beginning the lab, I set the objectives I wanted to achieve in the static and dynamic fluid experiments.
	6	I developed a step-by-step plan for the experiment before conducting observations.
	7	I estimated the time and equipment needed to complete the fluid experiment.
	8	I determined the most effective strategy to ensure accurate data.
Process monitoring	9	I review each step I take during the experiment.
	10	I identify any errors that may have occurred when measuring fluid pressure or velocity.
	11	I assess how well I understand the observations I make during the activity.
	12	I adjust my actions if I find that the experimental results do not align with my initial predictions.
Evaluation / reflection	13	After completing the experiment, I assessed whether my learning objectives had been achieved.
	14	I evaluated the reliability of the data I obtained from the fluid experiment.
	15	I reflected on any errors that occurred to improve my strategy for the next activity.
	16	I wrote a conclusion based on the results and the experimental process.
Strategic regulation / control	17	I change my work methods or steps if the previous method is ineffective.
	18	I use different strategies when experimental data is inconsistent.
	19	I correct errors in pressure or volume measurements when I find discrepancies.
	20	I adjust my learning strategies when I have difficulty understanding fluid concepts.
Cognitive representation and modeling	21	I can graph the relationship between pressure and fluid depth.
	22	I can explain fluid flow using simple diagrams or models.
	23	I use visual representations (tables/graphs) to facilitate analysis of experimental results.
Resource management and assistance	24	I use textbooks or online resources to understand fluid concepts I don't yet understand.
	25	I discuss with my classmates or teacher if I encounter difficulties during lab work.
	26	I use experimental equipment and materials efficiently to ensure the activity runs smoothly.
Emotional /cognitive regulation	27	I remain calm when experimental results do not align with my initial hypothesis.

	28	I am confident in presenting my observations and opinions to a group.
	29	I am able to control my anxiety when faced with errors in an experiment.
	30	I feel motivated to correct mistakes and try again until the results are better.

Source: prepared by researchers based on metacognitive skills indicators

The assessment of metacognitive skills in this study used a Likert scale of 1–4, with the following categories: 1 = never, indicating that students rarely or never demonstrate metacognitive behavior during learning or experimentation; 2 = poor, meaning that students sometimes recognize and use metacognitive skills but are not yet consistent; 3 = good, meaning that students frequently demonstrate metacognitive skills, although they may still require teacher guidance; and 4 = very good, indicating that students consistently, independently, and reflectively apply metacognitive skills throughout all stages of learning. This scale was used to provide a more objective and measurable representation of students' metacognitive ability levels. The metacognitive skills questionnaire used in this study underwent content validity testing involving two experts in physics education and instrument measurement.

The validation process was conducted to ensure that each questionnaire item aligned with the metacognitive skill indicators being measured and that it was clear, appropriate, and relevant to the research construct. The expert evaluation results showed that the first expert achieved a Percentage of Agreement (PSV) score of 90%, while the second achieved a score of 85%. The average content validity score of 87.5% indicates that the instrument falls within the "highly appropriate" category for use in data collection. This finding confirms that all questionnaire items meet the criteria of content relevance and construct alignment with the research objectives, ensuring that the instrument can be validly used to measure students' metacognitive skills.

Data Analysis

Data analysis in this study was carried out using an independent sample t-test. This analytical technique was selected to examine whether there were significant differences between two independent groups: those who received learning with iScan-MSL and those who learned without iScan-MSL. Before conducting the hypothesis test using the t-test, the data were evaluated to ensure that the fundamental assumptions were met, namely, normality of the data and homogeneous variance between groups. If both assumptions were met, the t-test was performed to compare the mean learning outcomes of the two groups.

Results

After all learning activities and data collection were completed, classical assumption testing was carried out using normality and homogeneity tests. These tests were applied to both the pretest and posttest scores, including students' metacognitive questionnaire scores and practicum performance results. The pretest data were analysed to ensure that the initial abilities of students in both groups were comparable, so that any differences in posttest results would accurately reflect the effect of the learning treatment using iScan-MSL. Meanwhile, posttest data were used to examine improvements in students' metacognitive skills following participation in the learning process.

Table 5

Results of the Normality Test of the Metacognitive Skills Pretest

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Practical	iScan-MSL	.089	51	.200*	.974	51	.319

	Non-iSCan-MSL	.098	51	.200*	.971	51	.233
Questionaire	iSCan-MSL	.114	51	.095	.964	51	.122
	Non-iSCan-MSL	.119	51	.066	.965	51	.139

Source: prepared by researchers from metacognitive skills pretest score data

Table 6

Results of the Homogeneity Test of Metacognitive Skills Pretest

	Levene Statistic	df1	df2	Sig.
Practical	1.321	1	100	.253
Questionaire	.337	1	100	.563

Source: prepared by researchers from metacognitive skills pretest score data

Table 7

Independent Sample t-test Pretest Metacognitive Skills

	Group	N	Mean	SD	t	df	p
Practical	iSCan-MSL	51	30.3431	6.78269	-.309	100	.758
	Non-iSCan-MSL	51	30.7843	7.62381			
Questionaire	iSCan-MSL	51	24.22	10.068	-.498 -.498	100 99.925	.619
	Non-iSCan-MSL	51	25.20	9.796			

Source: prepared by researchers from metacognitive skills pretest score data

The metacognitive skills pretest data collected and tested for normality are presented in Table 5. The table shows that the questionnaire score data obtained from the group that would receive learning using iScan-MSL yielded a significant result (Sig. = .095 > .050), and the group without the iScan-MSL model yielded a Sig. value of .066 > .050. The homogeneity test of the metacognitive skills questionnaire scores using Levene's test yielded a Sig. value of .563 > .050. Based on these results, the questionnaire score data for metacognitive skills were normally distributed and homogeneous. The students' practicum score data from the group that would learn using iScan-MSL also met the normality assumption, with a Sig. value of .200 > .050. Similarly, the group of students who would not use the iScan-MSL model in the learning process obtained a Sig. value of .200 > .050. The homogeneity test of the practicum scores using Levene's test yielded a Sig. Value of .253 > .050, indicating that the practicum data were also normally distributed and homogeneous.

After all pretest scores met the assumptions of normality and homogeneity, an independent-samples t-test was conducted. The results of the t-test are presented in Table 7. The pretest scores were analysed for both the metacognitive skills questionnaire and the students' practicum activity scores. In the practicum assessment, the group of students who would receive iScan-MSL instruction achieved a mean score of 30.34, while the group that would not use iScan-MSL achieved a mean score of 30.78. The t-test results showed a p-value of .758 > .050, indicating that the two groups had similar initial practicum performance.

In the questionnaire assessment, the group of students who would receive instruction using iScan-MSL achieved a mean score of 24.22, whereas the group that would not use the iScan-MSL model obtained a mean score of 25.20. The t-test results yielded a p-value of .619, which is> .050. This indicates that there was no significant difference in the two groups' initial metacognitive skills; both had similarly low baseline scores. Therefore, the pretest results confirm that students in both groups began with equivalent levels of metacognitive ability.

Table 8

Results of the Post-test Normality Test of Metacognitive Skills

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Practical	iSCan-MSL	.087	51	.200*	.980	51	.555
	Non-iSCan-MSL	.107	51	.200*	.970	51	.224
Questionaire	iSCan-MSL	.114	51	.097	.955	51	.052
	Non-iSCan-MSL	.109	51	.183	.963	51	.111

Source: prepared by researchers from post-test metacognitive skills data

Table 9

Results of the Homogeneity Test of Post-test Metacognitive Skills

	Levene Statistic	df1	df2	Sig.
Practical	1.858	1	100	.176
Questionaire	1.377	1	99	.243

Source: prepared by researchers from post-test metacognitive skills data

Table 10

Independent Sample t-test Post-test Metacognitive Skills

	Group	N	Mean	SD	t	df	p
Practical	iSCan-MSL	51	80.1961	6.47771	3.205	99	.002
	Non-iSCan-MSL	51	70.7353	7.60418	3.210	97.660	
Questionaire	iSCan-MSL	51	81.96	12.128	6.764	100	.000
	Non-iSCan-MSL	51	74.70	10.566			

Source: prepared by researchers from post-test metacognitive skills data

After each group completed the learning activities, final measurements were conducted through practicum activities and the administration of questionnaires as post-tests. The post-test score data were then collected and analysed. The students' metacognitive skills scores were tested for normality, as presented in Table 8. The table shows that the group of students who participated in learning using iSCan-MSL obtained normality test results of Sig. .200 > .050 for questionnaire scores and Sig. .097 > .050 for practicum scores. Meanwhile, the group of students who were taught without iSCan-MSL obtained Sig. .200 > .050 for questionnaire scores and Sig. .183 > .050 for practicum scores. The homogeneity test results in Table 9 show that the practicum scores yielded Sig. .176 > .050 in Levene's test, and the questionnaire scores yielded Sig. .243 > .050. Based on these classical assumption tests, all post-test data were normally distributed and homogeneous.

The results of the independent sample t-test presented in Table 10 show that the practicum scores of students taught using iSCan-MSL mean 80.19, while those taught without iSCan-MSL mean 70.73. The t-test results indicated a p-value of .002, which is < .050. Based on the practicum results, there was a significant difference in metacognitive skill scores between the two groups, with the iSCan-MSL group achieving higher performance.

Furthermore, based on the results of the metacognitive skills questionnaire, students taught with iSCan-MSL achieved a mean score of 81.96. In contrast, those taught conventionally without iSCan-MSL achieved a mean score of 74.70. The t-test results showed a p-value of <.050. These findings indicate that the group that received learning with iSCan-MSL achieved better metacognitive skills. Overall, the t-test results confirm that the iSCan-MSL model had a significant influence on students' metacognitive skills.

Discussion

In the practical aspect, the group using the iSCan–Mobile Seamless Learning (MSL) model (mean = 80.19) achieved a significantly higher score than the control group (mean = 70.73), with a p-value of 0.002 (<0.05), indicating a statistically significant difference. These results support existing findings that learning designs that integrate seamless mobile learning and metacognitive strategies can enhance students' scientific thinking skills in physics (Reinhard et al., 2022; Sijmkens et al., 2023). For example, research has Zharylgapova et al. (2025) demonstrated that mobile applications in physics learning have a substantial positive impact on students' cognitive abilities. In addition, the incorporation of metacognitive prompts or scaffolding in digital learning environments has been shown to strengthen students' planning, monitoring, and evaluation strategies (Juhaňák et al., 2025; Krieglstein et al., 2023; Zeitlhofer et al., 2023). Furthermore, the literature on metacognition suggests that students with higher levels of metacognitive awareness and regulation tend to achieve better outcomes in physics laboratory activities (Stanton et al., 2021). Thus, the iSCan-MSL intervention appears effective in promoting both physics practice and continuous metacognitive reflection, thereby improving student performance.

Furthermore, the results of the metacognitive skills questionnaire showed that the iSCan-MSL group obtained an average score of 81.96, while the conventional group obtained 74.70, with p = 0.000 (< 0.05). This finding indicates that students who participated in learning with iSCan-MSL excelled in planning, monitoring, strategic regulation, and self-reflection (Cong et al., 2024; Zepeda & Nokes-Malach, 2023). This is consistent with the findings of Sapulete et al. (2024) those who reported that physics problem-solving strategies emphasising cognitive regulation improve students' metacognitive skills. It is also aligned with cross-national validation studies of the MAI instrument, which have demonstrated its robustness for mapping metacognitive awareness and regulation (Blume et al., 2024). Furthermore, the literature indicates that metacognition is a key predictor of scientific learning outcomes, especially when students are given opportunities to regulate their own learning processes (Willison et al., 2024). This is reinforced by recent standardisations of university-level metacognitive assessment protocols, which demonstrate the reliability of measuring monitoring and control strategies (Blume et al., 2023). Therefore, the iSCan-MSL model aligns with pedagogical practices that foster students' cognitive control and metacognitive awareness, including improvements in the accuracy of learning judgments through structured metacognitive prompts (Michalsky & Bakrish, 2024).

From a learning-theory perspective, results from both the practicum and questionnaire assessments indicate that integrating religious values, active learning strategies, exploration, collaboration, and mobile technology in iSCan-MSL enables students to construct knowledge more independently and reflectively (Pan et al., 2024). This approach is consistent with 21st-century learning principles that emphasise self-regulated and seamless learning. Recent reviews and empirical studies have shown that metacognitive scaffolding in technology-enhanced classrooms and computer simulations strengthens evidence-based feedback and supports higher-order learning strategies (Hartelt & Martens, 2024; Kaldaras et al., 2024). Collectively, recent evidence suggests that mobile learning contributes significantly to learning outcomes and the development of higher-order thinking skills, including metacognition. Recent mappings also indicate that technology-supported scaffolding designs that explicitly address metacognition are becoming increasingly dominant in K-12 research (Garzón et al., 2025). Thus, the success of this model confirms that religious contextualization and continuity of learning are key factors in enhancing students' scientific thinking skills.

However, this study has limitations related to the static and dynamic fluid laboratory activities, the eleventh-grade student population, and the duration of the intervention. A recent meta-analysis reported that interventions targeting monitoring accuracy, a core component of metacognition, produce small-to-moderate positive effects and are influenced by the type and scope of the learning task. Therefore, interpretation across different physics topics should be approached with caution (Janssen & Lazonder, 2024). The metacognition literature also emphasises that the development of strategic regulation and reflective thinking requires time and repeated practice, involving complex neurocognitive processes in monitoring (e.g., judgments of learning) (Cong et al., 2024). Thus, although the results of this study are positive, generalising them to other physics concepts or educational levels should be done cautiously, especially for younger learners whose monitoring and control processes follow distinctive developmental trajectories (Eberhart et al., 2025; van Loon & Roebers, 2024). Meta-analytic evidence on reflective interventions also highlights that duration and learning mode act as moderators, suggesting that future interventions should consider intensity and sustainability (Zhai et al., 2023). Future research could also explore moderating variables such as digital literacy, learning culture, or intervention continuity. Developmental trends over a 4–6-year span show a shift from implicit monitoring to more explicit control, indicating the importance of stepwise intervention designs (S. Chen et al., 2025).

Implications: The findings of this study provide both theoretical and practical contributions. Theoretically, they reinforce evidence that metacognition and strategic regulation are essential components of physics learning, especially when integrated with seamless mobile learning. They also highlight the role of teacher scaffolding in supporting monitoring and metastrategic decision-making in the classroom (Li et al., 2024). In practice, physics teachers can apply the iSCan-MSL model to design more reflective, collaborative, and technology-supported learning to enhance students' metacognitive skills, supported by metacognitive scaffolding in mobile or interactive learning environments (Pan et al., 2024). It is recommended that teacher training on metacognitive scaffolding and seamless/mobile learning be enhanced by incorporating reflective prompts, which have been shown to improve preservice teachers' metacognitive capacity (Chaseley & Abercrombie, 2025). Furthermore, the application of metacognitive scaffolding in project-based learning has been found to support strategic skills—planning, monitoring, and evaluating—in structured problem-solving, which is relevant in practical physics contexts (Wang et al., 2023). Finally, recent studies highlight opportunities to use learning analytics and AI to ethically and constructively scaffold metacognition in STEM learning ecosystems, which may be integrated into teacher professional development programs (Tsakeni et al., 2025).

Conclusions

This study examined the effect of the iSCan–Mobile Seamless Learning model on students' metacognitive skills in physics learning, specifically targeting the indicators of planning, monitoring, and evaluation. Overall, the findings demonstrate that the proposed model significantly enhances students' ability to regulate their thinking during the learning process. These results confirm that learning activities designed with continuous scaffolding both inside and outside the classroom can effectively support students in managing their cognitive strategies in line with the research aims and questions. The scientific novelty of this study lies in integrating the seamless learning environment with explicit metacognitive prompts embedded in the iSCan learning cycle. Unlike conventional face-to-face instruction, this model provides continuous opportunities for students to plan learning goals, monitor understanding in real time, and evaluate their outcomes through reflective tasks. The improvements observed in all three indicators highlight the pedagogical contribution of the iSCan–MSL model as an innovative approach to optimising students' metacognitive regulation in physics contexts.

Despite its contributions, this study has several limitations. The intervention was conducted within a single-school context and with a limited sample size, which may limit the generalizability of the findings. Additionally, the measurement of metacognitive skills relied primarily on self-report instruments and rubric-based task performance, which may not fully capture students' cognitive processes in real time. Future research is recommended to involve larger and more diverse participant groups, and to incorporate advanced measurement techniques, such as learning analytics and trace data, to provide deeper insights into students' metacognitive behaviours. Exploring the long-term effects of the iSCan–MSL model would also be valuable for determining retention and sustainability of skills across physics topics and different learning environments.

Suggestions for future research

The findings of this study provide essential theoretical and practical implications for the development of students' metacognitive skills. Theoretically, the results confirm that the iSCan–MSL model can strengthen students' awareness of and regulation of their thinking through integrated, continuous learning activities. This model allows students to actively plan, monitor, and evaluate their learning processes in a flexible environment spanning both formal and informal settings. Practically, the implementation of iSCan–MSL offers opportunities for teachers to design learning experiences that promote self-reflection and regulation through mobile technology–based learning strategies, enabling students to develop greater independence and control over their cognitive processes.

Future research may focus on expanding the application of the iSCan–MSL model across various science domains and educational levels to examine its consistent effectiveness in enhancing metacognitive skills. Longitudinal studies are also recommended to evaluate the sustainability of the learning effects on students' metacognitive development. Additionally, incorporating mediating variables such as motivation, self-efficacy, or cognitive engagement may deepen understanding of the mechanisms linking the model's implementation to metacognitive outcomes. Learning analytics or artificial intelligence–based approaches could also be developed to monitor metacognitive awareness in real time and provide adaptive feedback to support more personalised learning.

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Conflict of Interest

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