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Title and Abstract

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Abstract: This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' high order thinking skills (HOTS). The analyze, design, develop, implement, and evaluate (ADDIE) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a general linear model and multivariate analysis of variance. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' HOTS. The ADDIE (analyze, design, develop, implement, and evaluate) model was employed in this study. Needs analysis was conducted through interviews and questionnaire surveys to 21 students from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. Expert validation was conducted with seven educational experts using the Dhelphi technique. The model's construct validity was evaluated using randomly selected classrooms from two different institutions, while the model's content validity was checked using the Aiken's V formula (content-validity coefficient (V)). The effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students) and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a General Linear Model and Multivariate Analysis of Variance (MANOVA), followed by an effect size analysis utilizing Cohen's d to ascertain the model's effect on students' HOTS. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgement indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers to master. In the department of primary school teacher education (PSTE) in Indonesia, science education is offered through courses that emphasize science principles, science education, and the development of science instruction.

These courses are geared toward increasing the technological, pedagogical content knowledge (TPACK) of the students. Graduates of the PSTE department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the PSTE department should also develop higher order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [1], face difficulty learning science (Maryani, Husna, Wangid, Mustadi, & Vahechart, 2018), and have poor performance in science.

In addition, the occurrence of the Covid-19 Pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision making skills, and thinking skills, which are also known as 21st century skills.

The twenty-first century skills have become a topic of discussion among several educational institutions, practitioners, and experts. According to Trisdiono (2013), the 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills. In addition, ATC21S (Assessment & Teaching of 21st Century Skills) classifies the 21st century skills into four areas; one of which is methods of thinking [4]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS (High-order Thinking Skills).

Learning that continues to emphasize the development of lowerlevel thinking skills (LOTS) contributes to the poor higher order thinking skills (HOTS) of teachers in Indonesia [5]. Many university teachers continue to struggle with teaching HOTS and preparing their students to use higher order thinking in everyday life. This could be due to the instructors' lack of expertise regarding how to hone students' higher order thinking skills [6]. According to studies [7], [8], the LOTS group contains a greater number of future primary school teachers/PSTE students than the HOTS category. Because of this, the learning process in higher education should not only prioritize cognitive processes but also foster students' learning awareness and independence.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting higher order thinking skills (HOTS) in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as PBL [9], RMS (Reading, Mapping, and Sharing) [10], CUPs (Conceptual Understanding Procedures) [11], Constructive Conflict (CC) and Modified Free Inquiry (MFI) [12], FILM [13], and Guided Inquiry Laboratory-Based Module (GILM [14] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: 1) help students monitor their progress and control their learning process (through reading, writing, solving problems); 2) contribute to students' learning desire above their intellectual abilities [15], [16]; 3) improve academic achievement across age, cognitive abilities, and learning domains [17], [18]; and 4) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities such as: 1) reflecting on the thought processes involved in the learning process; 2) seeking concrete examples from prior learning experiences and mindsets; 3) analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; 4) making generalizations and formulating rules about these thought patterns; and 5) naming the thought pattern [19]–[21]. This integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously.

Research Questions

1. What role does metacognition play in an online learning model?
2. To what extent is a metacognition-integrated online learning effective in promoting students' higher order thinking skills (HOTS) in science?

2. THEORITICAL FRAMEWORK

2.1. Science Education

Science is a field of study that is concerned with natural phenomena. Science is the methodical examination of nature's structure and behavior as observed using the scientific method. Science is divided into three domains: a body of knowledge, a collection of methods and procedures, and a mode of knowing about nature [22]. A collection of definitions, facts, concepts, theories, and laws constitutes a body of knowledge. A set of methods and processes includes observing, measuring, estimating, estimating, inferring, predicting, classifying, hypothesizing, experimenting, and concluding. A way of knowing about nature is founded on the premise that scientific knowledge is evidence-based, scientific information can survive over time, creativity is critical in research, and background knowledge influences how scientists interpret data [23]. All explanations in science are founded on observations and experiments that can be conducted and verified by scientists. This cannot be a simply empirical explanation [24]. Based on this perspective, students studying science are placed in problem-solving settings. This predicament is aided by educational materials that teach pupils how to process information scientifically [25].

Science education attempts to naturally stimulate students' curiosity. Science education is used to strengthen students' abilities to ask probing questions and seek evidence-based answers regarding natural events, as well as to foster the development of scientific thinking. Science is used to understand the world and move forward as a systematic effort to develop reason. Scientific processes can be used to develop reason [26]. Science is useful for growing awareness and caring attitude of students in maintaining and preserving nature through investigation. This favorable attitude is formed through the implementation of knowledge and process skills in solving contextual problems.

2.2. Metakognisi

Metacognition is defined as the capacity for self-awareness and control over one's own learning [27]. Metacognition is concerned with processes occurring on an individual level. Flavell (1979) in [28] describes metacognition as awareness of how one learns; when one understands and does not understand; knowledge of how to use available information to accomplish goals; the ability to assess the cognitive demands of a particular task; knowledge of which strategies are used for what purposes; and assessment of one's progress during and after performance.

Metacognition is divided into two significant components: metacognitive knowledge and metacognitive regulation [29], [30]. Metacognitive knowledge refers to an understanding of aspects that can be used to influence cognitive processes [31]. Metacognitive knowledge is the capacity to comprehend how numerous elements interact to influence our own thinking [32]. Metacognitive knowledge consists of awareness of knowledge/person variables, awareness of thinking/task variables, and awareness of thinking/strategy variables. Declarative knowledge, procedural knowledge, and conditional knowledge are all examples of metacognitive knowledge. All three are stages of metacognitive understanding on the way to metacognitive regulation. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. Metacognitive regulation is a term that refers to the process of monitoring cognitive activity and ascertaining whether cognitive objectives have been met [33]. In science learning, metacognitive abilities place a greater emphasis on the process than on the product. Metacognitive strategies play a critical part in successful learning by enhancing students' metacognitive abilities. If teachers can foster metacognitive skills in their students, they can lay the groundwork for active and skillful learning.

A metacognition-integrated learning model has several components, including planning, monitoring, and evaluating. The planning tasks in question are as follows: 1) establishing goals to be reached, 2) arranging the time required to accomplish the goals, 3) acquiring necessary knowledge to reach the goals, and 4) planning and deciding on cognitive techniques to achieve the goals. The monitoring activities are as follows: 1) monitoring the objectives to be accomplished, 2) monitoring the amount of time spent, 3) measuring the adequacy of initial information, and 4) monitoring the implementation of cognitive techniques. The evaluation activities in question are as follows: 1) assessing target attainment, 2) assessing time management, 3) assessing the relevance of prior knowledge, and 4) assessing the effectiveness of cognitive techniques applied [34].

A benefit of the metacognitive strategies is that it promotes learner autonomy. Additionally, metacognition can assist students in tracking their progress and exerting control over their learning process (through reading, writing, solving problems). Metacognitive abilities of students contribute to their desire/interest in learning. Metacognition has been shown to compensate for cognitive deficiencies (Veenman et al., 2006; Veenman et al., 2004)and to improve academic achievement across age, cognitive capacities, and domains of learning. Metacognition also benefits reading, writing, mathematics, reasoning, problem solving, and memory abilities [17], [18]. Metacognition is also influenced by age and views regarding the critical role of self-efficacy in determining one's success [36]. Metacognition techniques can activate components of metacognitive abilities, allowing for the optimization of an individual's fundamental skills (reading and mathematics) [37]. Metacognition contributes to group and individual performance by altering the structure of knowledge through metacognitive activities [38].

2.3. *Higher-Order Thinking Skills (HOTS)*

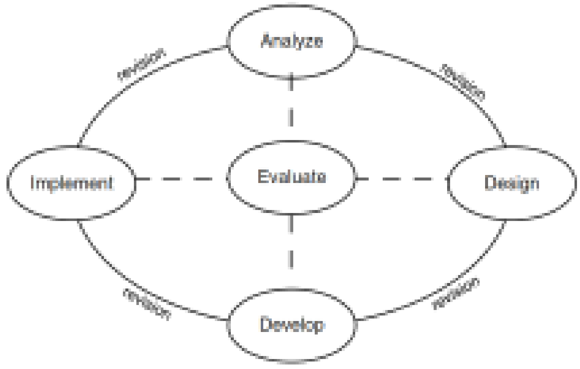
Higher order thinking skills (HOTS) are significantly more advanced than memorization. These skills need a range of mental processes, including analyzing, evaluating, and creating, all of which are embedded within the problem-solving process. The ability to involve analysis, evaluation, and creation is considered a higher order thinking ability [39]. Higher order thinking happens at a more advanced stage of the cognitive process hierarchy. The most frequently regarded hierarchical structure in education is Bloom''s Taxonomy, which ranks thinking abilities from understanding to evaluation [40]. However, the new paradigm of educational research frequently references Marzano's Taxonomy's definition of HOTS, which includes comparing, classifying, inductive reasoning, deductive reasoning, error analysis, construction support, perspective analysis, abstracting, decision making, investigation, problem solving, experimental inquiry, and invention [41]–[44].

Additionally, students' higher order thinking skills (HOTS) can be enhanced by the inclusion of technology in the learning process. Numerous studies have demonstrated success in improving students' HOTS with the use of technology, including the use of Android-based worksheets to foster creativity, which has a positive effect on HOTS [45]. Additionally, I. Yusuf & Widyaningsih (2019) increased students' HOTS in Physics by implementing STEM with the assistance of PhET media. Another study was conducted on a quantum physics course, demonstrating that using the STEM approach via e-learning can promote HOTS [47]. Alsowat (2016) established a highly significant correlation between HOTS and student engagement, HOTS and student contentment, and student involvement and satisfaction in an EFL postgraduate class using the Flipped Classroom Teaching Model (FCTM).

In an experimental activity, evaluation of the learning process can also be used as a strategy to empower HOTS through concept maps (mind mapping). The thought processes involved when students construct a concept map can be explored and studied in detail using a higher-thinking protocol. This activity can demonstrate growth in students' comprehension and higher order thinking skills. Students that excel academically are more likely to provide explanations and participate actively in mind mapping. Assessment using concept maps in laboratory learning activities can improve students' comprehension and increases students' HOTS [49].

3. RESEARCH METHODS

The current R&D study used the ADDIE (Analysis, Design, Develop, Implement, dan Evaluate) model [50] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.



Source: [50]

Figure 1. The R&D ADDIE model

The urgency of developing the learning model as well as problem analysis were carried out at the *Analyze* stage. At the *Design* stage, the product's design and draft were created. At the *Develop* stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both content (expert judgment) and construct (experimental study). The process of implementing the learning model on a wider scale is carried out at the *Implement* stage.

Needs analysis was conducted through interviews and questionnaires at 21 departments of primary school teacher education in 7 state universities and 14 private universities in Indonesia. Expert validation with the Dhelphi technique involved 7 education experts, while the effectiveness of the model was tested through an experimental study on 3 groups of students. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan and Universitas Bachelorwiyata Tamansuswa. The experimental study employed a randomized Pretest-Post-test Comparison Group Design suggested by [51]. The study involved 41 students as the experimental group, 39 students as the control group 1 and 39 students as the control group 2. The Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The following equation represents the content-validity coefficient (V):

$$\mathbf{V} = \frac{\Sigma \mathbf{s}}{[\mathbf{n}(\mathbf{c}-\mathbf{1})]} \qquad \mathbf{(1)}$$

Remarks:

Io = the lowest validity score (in this case = 1)
c = the highest validity score (in this case = 5)
r = expert judgment score
s = r – Io
c = number of experts
V = content-validity coefficient (between 0-1) [52]

Hypothesis testing to find the effect of metacognition integration in online science learning on college students' HOTS was carried out using the General Linear Model and the Multivariate Analysis of Variance (Manova). MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the Effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [53]–[55].

4. RESULT AND DISCUSSION

4.1. Result

4.1.1 The Analyze Stage

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education (PSTE) programs at seven public universities and fourteen private universities in Indonesia revealed that PSTE students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of a material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement (Maryani et al., 2021).

4.1.2 The Design Stage

The design of the metacognition-integrated science learning model (MiSHE) produced in the *Design* stage is shown in Figure 2.

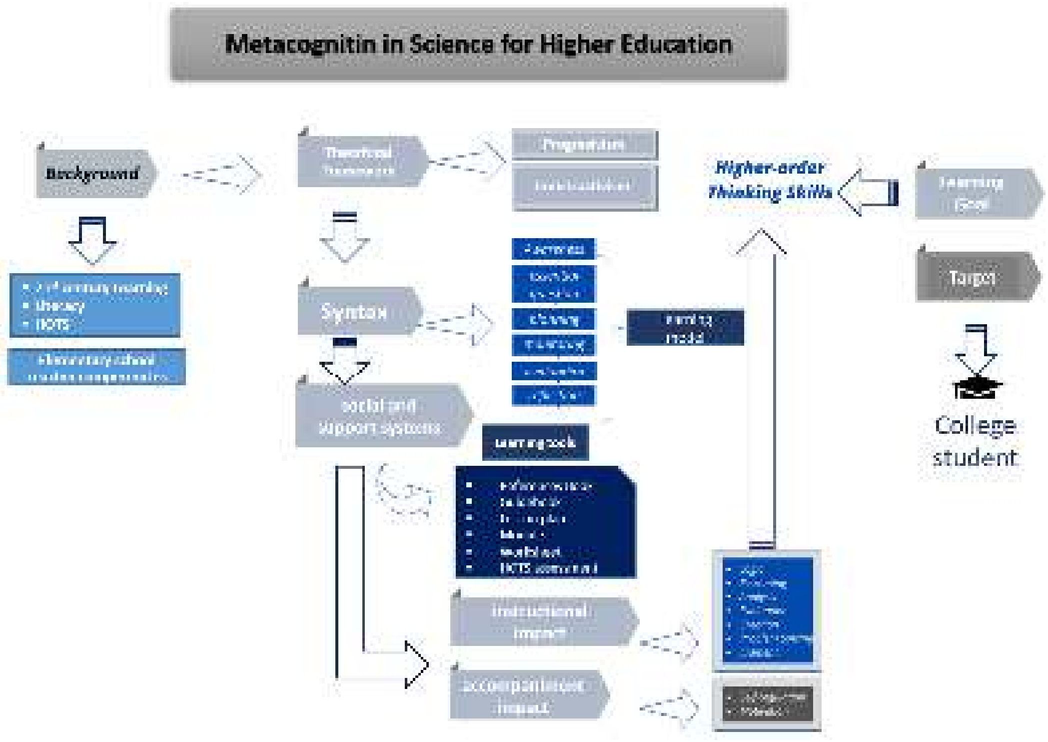


Figure 2. The MiSHE Learning Model's Design

The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' higher order thinking skills (HOTS). The lesson plan comprises of 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, Learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the MiSHE project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project.

4.1.3 The Develop Stage

The *Develop* Stage generated the data on the model's content and construct validity test results.

Table 1. Expert Judgement on the Model's Content Validity

Product	Aspect	V-Score	Criteria
The Model's Book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language Use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language Use	0.911	Valid (high)
RPS		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring in order to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the PhET simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to [57] criteria for practicality, the MiSHE learning model was implemented successfully for the students that participated in this study.

To investigate the extent of the treatment impact, hypotheses were tested using the General Linear Model (GLM) and Multivariate of Variance (MANOVA). Four assumptions must be met for this test to be valid: 1) an independent observer, 2) a random sample, and 3) normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (< 0.05). In an experimental study, the error factor (subject, sample, treatment, etc.) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [58]. (Blanca et al., (2017) confirm this point by stating that the uniformity of data in an experiment can be overlooked. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [60].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by Tests of Within-Subjects Effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the Mean Different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14,923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS (Table 2).

Table 2.Multivariate Tests

Multivariate Tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
experiment	Pillai's trace	,745	45,419^{a}	7,000	109,000	,000	,745
	Wilks' lambda	,255	45,419^{a}	7,000	109,000	,000	,745
	Hotelling's trace	2,917	45,419^{a}	7,000	109,000	,000	,745
	Roy's largest root	2,917	45,419^{a}	7,000	109,000	,000	,745
Control 1	Pillai's trace	,354	8,530^{a}	7,000	109,000	,000	,354
	Wilks' lambda	,646	8,530^{a}	7,000	109,000	,000	,354
	Hotelling's trace	,548	8,530^{a}	7,000	109,000	,000	,354
	Roy's largest root	,548	8,530^{a}	7,000	109,000	,000	,354
Control 2	Pillai's trace	,684	33,638^{a}	7,000	109,000	,000	,684
	Wilks' lambda	,316	33,638^{a}	7,000	109,000	,000	,684
	Hotelling's trace	2,160	33,638^{a}	7,000	109,000	,000	,684
	Roy's largest root	2,160	33,638^{a}	7,000	109,000	,000	,684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column as suggested by Leech et al (2013). Partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. Based on Bakker et al., (2019), Cohen (1988), dan Mordkoff (2019), the value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5). The effect size of the metacognition integrated learning model on students' HOTS was quite large because it was more than 50%. The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

4.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' higher order thinking skills (HOTS) to solve problems and make sound decisions in their life after graduation. Higher order thinking skills (HOTS) are inextricably linked to technological, pedagogical, and content knowledge (TPACK) [62], [63]. These abilities are critical for developing students' problem-solving abilities [47]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [64], which is especially critical in elementary school science instruction.

Syntax of the learning model established in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: 1) awareness of knowledge/person factors, 2) awareness of thought/task variables, and 3) awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [31]. These three elements are represented in the MiSHE learning model's *awareness building* step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [33].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [19]–[21]. Planning, monitoring, and assessing are all components of metacognition [34]. The three are then included into the MiSHE learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, Phet, and sound meter software, as well as video presentation projects are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness building) in relation to the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' higher order thinking skills (HOTS) in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occuring around them [65]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mindmapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers in order to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [66], [67]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems (Özreçberoğlu & Çağsanağa, 2018).

The advantages of the metacognition-integrated learning model are as follows: (1) the model was developed using scientific procedures that are quantifiable and involve experts; (2) the model can be implemented in normal or pandemic conditions by adjusting the learning activities; 3) the learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; 4) the learning model was designed based on real-world situations; 5) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

5. *Conclusion*

Metacognition can be integrated into online science learning through awareness-raising, critical questioning, planning, monitoring, evaluating, and reflecting. We developed lesson plans and teaching materials in this study with reference to this syntax via instructional activities that strengthen metacognitive skills. Expert judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' higher order thinking skills (HOTS), as seen by a 75% (large effect) increase in response to the model's application. Changes in student behavior and character that appeared during the application of the MiSHE learning model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation.

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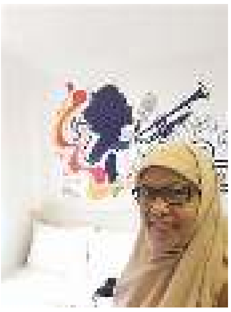

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Editor/Author Correspondence

Author 2021-11-11 07:34 AM

Subject: Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

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#23129 Review

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Section	Educational Approaches
Editor	Rafael Denadai (Review) Lena Lindenskov, Ph.D. (Review) Maja Ljubetic, Ph.D (Review) Asghar Soltani, Ph.D. (Review)

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Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

Ika Maryani[1], Zuhdan Kun Prasetyo[2], Insih Wilujeng[3], Siwi Purwanti[4]

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' HOTS. The ADDIE (analyze, design, develop, implement, and evaluate) model was employed in this study. Needs analysis was conducted through interviews and questionnaire surveys to 21 students from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. Expert validation was conducted with se educational experts using the Dhelphi technique. The model's constr validity was evaluated using randomly selected classrooms from two differ institutions, while the model's content validity was checked using the Aik V formula (content-validity coefficient (V)). The effectiveness of the mo was examined through an experimental study involving three groups students: experimental group (41 students), control group 1 (39 students) control group 2 (39 students). The experimental study was performed us the randomized pretest-posttest comparison group design. The resea hypothesis was investigated using a General Linear Model and Multivar Analysis of Variance (MANOVA), followed by an effect size analysis utilizing Cohen's d to ascertain the model's effect on students' HOTS. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgement indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers to master. In the department of primary school teacher education (PSTE) in Indonesia, science education is offered through courses that emphasize science principles, science education, and the development of science instruction.

Commented [A1]: Is it representative of the population? Because it only involved 21 students from 21 universities. The assumption means that 1 college involves 1 student. Too small for the size of a preliminary study in RND . research

Commented [A2]: why only involved 7 experts (academics) who all came from the field of mathematics education. while speaking of HOTS, academics from mathematics and teachers who know the field conditions are needed

Commented [A3]: at what phase is it effective? develop, implement or evaluate

Commented [A4]: in addition to what is in the comments in the introduction, you need to improve the writing with the following:

- state the research contributions more clearly
- align the abstract to the contents of your article
- be precise about how the research was conducted
- identify the research gap and the goals of the research
- describe knowledge acquisition behaviour concisely
- correct grammar and punctuation errors

Commented [A5]: what do you mean by master here?

Commented [A6]: does this happen in all universities, or only in one university?

These courses are geared toward increasing the technological, pedagogical content knowledge (TPACK) of the students. Graduates of the PSTE department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the PSTE department should also develop higher order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [1], face difficulty learning science (Maryani, Husna, Wangid, Mustadi, & Vahechart, 2018), and have poor performance in science.

In addition, the occurrence of the Covid-19 Pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision making skills, and thinking skills, which are also known as 21st century skills.

The twenty-first century skills have become a topic of discussion among several educational institutions, practitioners, and experts. According to Trisdiono (2013), the 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills. In addition, ATC21S (Assessment & Teaching of 21st Century Skills) classifies the 21st century skills into four areas; one of which is methods of thinking [4]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS (High-order Thinking Skills).

Learning that continues to emphasize the development of lowerlevel thinking skills (LOTS) contributes to the poor higher order thinking skills (HOTS) of teachers in Indonesia [5]. Many university teachers continue to struggle with teaching HOTS and preparing their students to use higher order thinking in everyday life. This could be due to the instructors' lack of expertise regarding how to hone students' higher order thinking skills [6]. According to studies [7], [8], the LOTS group contains a greater number of future primary school teachers/PSTE students than the HOTS category. Because of this, the learning process in higher education should not only prioritize cognitive processes but also foster students' learning awareness and independence.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting higher order thinking skills (HOTS) in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as PBL [9], RMS (Reading, Mapping, and Sharing) [10], CUPs (Conceptual Understanding Procedures) [11], Constructive Conflict (CC) and Modified Free Inquiry (MFI) [12], FILM [13], and Guided Inquiry Laboratory-Based Module (GILM [14] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: 1) help students monitor their progress and control their learning process (through reading, writing, solving problems); 2) contribute to students' learning desire above their intellectual abilities [15], [16]; 3) improve academic achievement across age, cognitive abilities, and learning domains [17], [18]; and 4) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities such as: 1) reflecting on the thought processes involved in the learning process; 2) seeking concrete examples from prior learning experiences and mindsets; 3) analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; 4) making generalizations and formulating rules about these thought patterns; and 5) naming the thought pattern [19]–[21]. This

Commented [A7]: it is necessary to write down where is the link between the course and the TPACK ability? As far as I know, the Constitutional Court is directed to master science knowledge

Commented [A8]: HOTS and LOTS including ways of thinking or types of problems or levels of thinking?

integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously.

Research Questions

1. What role does metacognition play in an online learning model?
2. To what extent is a metacognition-integrated online learning effective in promoting students' higher order thinking skills (HOTS) in science?

2. THEORITICAL FRAMEWORK

2.1. Science Education

Science is a field of study that is concerned with natural phenomena. Science is the methodical examination of nature's structure and behavior as observed using the scientific method. Science is divided into three domains: a body of knowledge, a collection of methods and procedures, and a mode of knowing about nature [22]. A collection of definitions, facts, concepts, theories, and laws constitutes a body of knowledge. A set of methods and processes includes observing, measuring, estimating, estimating, inferring, predicting, classifying, hypothesizing, experimenting, and concluding. A way of knowing about nature is founded on the premise that scientific knowledge is evidence-based, scientific information can survive over time, creativity is critical in research, and background knowledge influences how scientists interpret data [23]. All explanations in science are founded on observations and experiments that can be conducted and verified by scientists. This cannot be a simply empirical explanation [24]. Based on this perspective, students studying science are placed in problem-solving settings. This predicament is aided by educational materials that teach pupils how to process information scientifically [25].

Science education attempts to naturally stimulate students' curiosity. Science education is used to strengthen students' abilities to ask probing questions and seek evidence-based answers regarding natural events, as well as to foster the development of scientific thinking. Science is used to understand the world and move forward as a systematic effort to develop reason. Scientific processes can be used to develop reason [26]. Science is useful for growing awareness and caring attitude of students in maintaining and preserving nature through investigation. This favorable attitude is formed through the implementation of knowledge and process skills in solving contextual problems.

2.2. Metakognisi

Commented [A9]: what is metakognisi?

Metacognition is defined as the capacity for self-awareness and control over one's own learning [27]. Metacognition is concerned with processes occurring on an individual level. Flavell (1979) in [28] describes metacognition as awareness of how one learns; when one understands and does not understand; knowledge of how to use available information to accomplish goals; the ability to assess the cognitive demands of a particular task; knowledge of which strategies are used for what purposes; and assessment of one's progress during and after performance.

Metacognition is divided into two significant components: metacognitive knowledge and metacognitive regulation [29], [30]. Metacognitive knowledge refers to an understanding of aspects that can be used to influence cognitive processes [31]. Metacognitive knowledge is the capacity to comprehend how numerous elements interact to influence our own thinking [32]. Metacognitive knowledge consists of awareness of knowledge/person variables, awareness of thinking/task variables, and awareness of thinking/strategy variables. Declarative knowledge, procedural knowledge, and conditional knowledge are all examples of metacognitive knowledge. All three are stages of metacognitive understanding on the way to metacognitive regulation. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. Metacognitive regulation is a term that refers to the process of monitoring cognitive activity and ascertaining whether cognitive objectives have been met [33]. In science learning, metacognitive abilities place a greater emphasis on the process than on the product. Metacognitive strategies play a critical part in successful learning by enhancing students' metacognitive abilities. If teachers can foster metacognitive skills in their students, they can lay the groundwork for active and skillful learning.

A metacognition-integrated learning model has several components, including planning, monitoring, and evaluating. The planning tasks in question are as follows: 1) establishing goals to be reached, 2) arranging the time required to accomplish the goals, 3) acquiring necessary knowledge to reach the goals, and 4) planning and deciding on cognitive techniques to achieve the goals. The monitoring activities are as follows: 1) monitoring the objectives to be accomplished, 2) monitoring the amount of time spent, 3) measuring the adequacy of initial information, and 4) monitoring the implementation of cognitive techniques. The evaluation activities in question are as follows: 1) assessing target attainment, 2) assessing time management, 3) assessing the relevance of prior knowledge, and 4) assessing the effectiveness of cognitive techniques applied [34].

A benefit of the metacognitive strategies is that it promotes learner autonomy. Additionally, metacognition can assist students in tracking their progress and exerting control over their learning process (through reading, writing, solving problems). Metacognitive abilities of students contribute to their desire/interest in learning. Metacognition has been shown to compensate for cognitive deficiencies (Veenman et al., 2006; Veenman et al., 2004)and to improve academic achievement across age, cognitive capacities, and domains of learning. Metacognition also benefits reading, writing, mathematics, reasoning, problem solving, and memory abilities [17], [18]. Metacognition is also influenced by age and views regarding the critical role of self-efficacy in determining one's success [36]. Metacognition techniques can activate components of metacognitive abilities, allowing for the optimization of an individual's fundamental skills (reading and mathematics) [37]. Metacognition contributes to group and individual performance by altering the structure of knowledge through metacognitive activities [38].

2.3. *Higher-Order Thinking Skills (HOTS)*

Higher order thinking skills (HOTS) are significantly more advanced than memorization. These skills need a range of mental processes, including analyzing, evaluating, and creating, all of which are embedded within the problem-solving process. The ability to involve analysis, evaluation, and creation is considered a higher order thinking ability [39]. Higher order thinking happens at a more advanced stage of the cognitive process hierarchy. The most frequently regarded hierarchical structure in education is Bloom''s Taxonomy, which ranks thinking abilities from understanding to evaluation [40]. However, the new paradigm of educational research frequently references Marzano's Taxonomy's definition of HOTS, which includes comparing, classifying, inductive reasoning, deductive reasoning, error analysis, construction support, perspective analysis, abstracting, decision making, investigation, problem solving, experimental inquiry, and invention [41]–[44].

Additionally, students' higher order thinking skills (HOTS) can be enhanced by the inclusion of technology in the learning process. Numerous studies have demonstrated success in improving students' HOTS with the use of technology, including the use of Android-based worksheets to foster creativity, which has a positive effect on HOTS [45]. Additionally, I. Yusuf & Widyaningsih (2019) increased students' HOTS in Physics by implementing STEM with the assistance of PhET media. Another study was conducted on a quantum physics course, demonstrating that using the STEM approach via e-learning can promote HOTS [47]. Alsowat (2016) established a highly significant correlation between HOTS and student engagement, HOTS and student contentment, and student involvement and satisfaction in an EFL postgraduate class using the Flipped Classroom Teaching Model (FCTM).

In an experimental activity, evaluation of the learning process can also be used as a strategy to empower HOTS through concept maps (mind mapping). The thought processes involved when students construct a concept map can be explored and studied in detail using a higher-thinking protocol. This activity can demonstrate growth in students' comprehension and higher order thinking skills. Students that excel academically are more likely to provide explanations and participate actively in mind mapping. Assessment using concept maps in laboratory learning activities can improve students' comprehension and increases students' HOTS [49].

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3. RESEARCH METHODS

The current R&D study used the ADDIE (Analysis, Design, Develop, Implement, dan Evaluate) model [50] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.

Source: [50]

Figure 1. The R&D ADDIE model

The urgency of developing the learning model as well as problem analysis were carried out at the *Analyze* stage. At the *Design* stage, the product's design and draft were created. At the *Develop* stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both content (expert judgment) and construct (experimental study). The process of implementing the learning model on a wider scale is carried out at the *Implement* stage.

Needs analysis was conducted through interviews and questionnaires at 21 departments of primary school teacher education in 7 state universities and 14 private universities in Indonesia. Expert validation with the Dhelphi technique involved 7 education experts, while the effectiveness of the model was tested through an experimental study on 3 groups of students. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan and Universitas Bachelorwiyata Tamansuswa. The experimental study employed a randomized Pretest-Post-test Comparison Group Design suggested by [51]. The study involved 41 students as the experimental group, 39 students as the control group 1 and 39 students as the control group 2. The Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The following equation represents the content-validity coefficient (V):

$$\mathbf{V} = \frac{\Sigma \mathbf{s}}{[\mathbf{n}(\mathbf{c}-\mathbf{1})]} \qquad (1)$$

Remarks:

Io = the lowest validity score (in this case = 1)
c = the highest validity score (in this case = 5)
r = expert judgment score
s = r – Io
c = number of experts
V = content-validity coefficient (between 0-1) [52]

Hypothesis testing to find the effect of metacognition integration in online science learning on college students' HOTS was carried out using the General Linear Model and the Multivariate Analysis of Variance (Manova). MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the Effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [53]–[55].

Commented [A11]: correct the grammar used. because the translation is not good

Commented [A12]: what are you doing at this stage? give an explanation

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Commented [A14]: what are you doing at this stage? give an explanation

Commented [A15]: what are you doing at this stage? give an explanation

Commented [A16]: because the steps used are ADDIE, but in its implementation only ADDIE cannot be called ADDIE. so it is necessary to explain the stages of evaluation like what?

Commented [A17]: 21 student or 21 department? consistency with abstract

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Commented [A20]: Why 3 groups? What are the characteristics of the subject?

Commented [A21]: which university is this?

Commented [A22]: what is construct validity used for?

Commented [A23]: which university is this?

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Commented [A25]: does this not "collapse" in rnd? because the need for analysis is not strong

Commented [A26]: content validity for what?

Commented [A27]: In RND research, at the need analysis stage, it should use in-depth qualitative research. Can it be generalized by using 21 students from 21 universities? Are the results believed to be used as a preliminary study to make a research design?

there is a plot that makes me a bit biased, in the need analysis used 21 students (coming from 21 universities) but in the trial it was carried out in 1 college. doesn't it shrink too much? Does it not make this RND research even more "collapsed" because the foundation at the need analysis stage is not strong.

Commented [A28]: does RND research have a hypothesis? if you have a hypothesis, isn't it only in the rnd stage? It means that not all ADDIE stages have a hypothesis. If it is assumed that all stages have a hypothesis, what about the Analysis stage, what is the hypothesis? as well as in other stages

4. RESULT AND DISCUSSION

4.1. Result

4.1.1 The Analyze Stage

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education (PSTE) programs at seven public universities and fourteen private universities in Indonesia revealed that PSTE students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of a material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement (Maryani et al., 2021).

4.1.2 The Design Stage

The design of the metacognition-integrated science learning model (MiSHE) produced in the *Design* stage is shown in Figure 2.

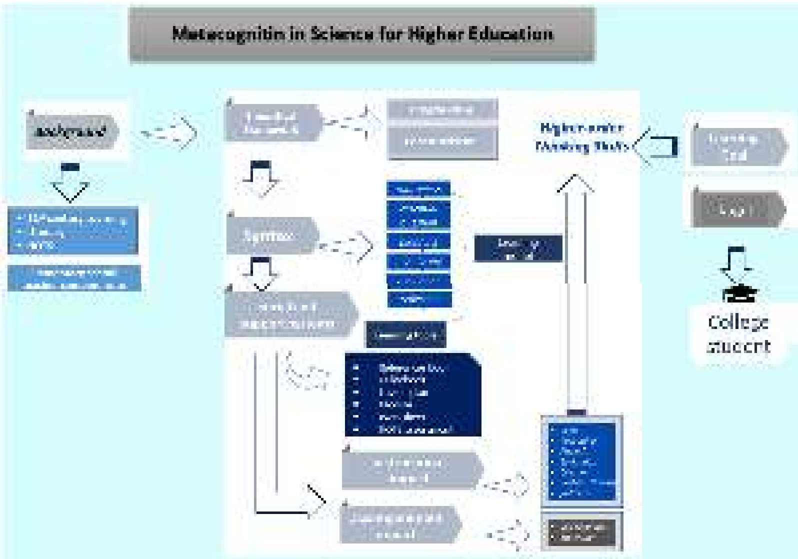

Figure 2. The MiSHE Learning Model's Design

The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' higher order thinking skills (HOTS). The lesson plan comprises of 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, Learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the MiSHE project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project.

4.1.3 The Develop Stage

The *Develop* Stage generated the data on the model's content and construct validity test results.

Table 1. Expert Judgement on the Model's Content Validity

Product	**Aspect**	**V-Score**	**Criteria**
The Model's Book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language Use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language Use	0.911	Valid (high)
RPS		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring in order to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the PhET simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to [57] criteria for practicality, the MiSHE learning model was implemented successfully for the students that participated in this study.

To investigate the extent of the treatment impact, hypotheses were tested using the General Linear Model (GLM) and Multivariate of Variance (MANOVA). Four assumptions must be met for this test to be valid: 1) an independent observer, 2) a random sample, and 3) normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (< 0.05). In an experimental study, the error factor (subject, sample, treatment, etc.) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [58]. (Blanca et al., (2017) confirm this point by stating that the uniformity of data in an experiment can be overlooked. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [60].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by Tests of Within-Subjects Effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the Mean Different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14,923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS (Table 2).

Table 2.Multivariate Tests

Multivariate Tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
experiment	Pillai's trace	,745	45,419[a]	7,000	109,000	,000	,745
	Wilks' lambda	,255	45,419[a]	7,000	109,000	,000	,745
	Hotelling's trace	2,917	45,419[a]	7,000	109,000	,000	,745
	Roy's largest root	2,917	45,419[a]	7,000	109,000	,000	,745
Control 1	Pillai's trace	,354	8,530[a]	7,000	109,000	,000	,354
	Wilks' lambda	,646	8,530[a]	7,000	109,000	,000	,354
	Hotelling's trace	,548	8,530[a]	7,000	109,000	,000	,354
	Roy's largest root	,548	8,530[a]	7,000	109,000	,000	,354
Control 2	Pillai's trace	,684	33,638[a]	7,000	109,000	,000	,684
	Wilks' lambda	,316	33,638[a]	7,000	109,000	,000	,684
	Hotelling's trace	2,160	33,638[a]	7,000	109,000	,000	,684
	Roy's largest root	2,160	33,638[a]	7,000	109,000	,000	,684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column as suggested by Leech et al (2013). Partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. Based on Bakker et al., (2019), Cohen (1988), dan Mordkoff (2019), the value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5). The effect size of the metacognition integrated learning model on students' HOTS was quite large because it was more than 50%. The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

4.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' higher order thinking skills (HOTS) to solve problems and make sound decisions in their life after graduation. Higher order thinking skills (HOTS) are inextricably linked to technological, pedagogical, and content knowledge (TPACK) [62], [63]. These abilities are critical for developing students' problem-solving abilities [47]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [64], which is especially critical in elementary school science instruction.

Syntax of the learning model established in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: 1) awareness of knowledge/person factors, 2) awareness of thought/task variables, and 3) awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [31]. These three elements are represented in the MiSHE learning model's *awareness building* step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [33].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [19]–[21]. Planning, monitoring, and assessing are all components of metacognition [34]. The three are then included into the MiSHE learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, Phet, and sound meter software, as well as video presentation projects are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness building) in relation to the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' higher order thinking skills (HOTS) in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occuring around them [65]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mindmapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers in order to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [66], [67]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems (Özreçberoğlu & Çağsanağa, 2018).

The advantages of the metacognition-integrated learning model are as follows: (1) the model was developed using scientific procedures that are quantifiable and involve experts; (2) the model can be implemented in normal or pandemic conditions by adjusting the learning activities; 3) the learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; 4) the learning model was designed based on real-world situations; 5) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

Commented [A29]: because at the research method stage, I think it's chaotic. then in this part need to adjust it

5. *Conclusion*

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- In your conclusion you need to include the newly formulated theoretical contributions
- Also, you need to list any limitations of the study and any prospects for future research
- You also need to include a summary of the key results in a compact form and re-emphasize their significance

Metacognition can be integrated into online science learning through awareness-raising, critical questioning, planning, monitoring, evaluating, and reflecting. We developed lesson plans and teaching materials in this study with reference to this syntax via instructional activities that strengthen metacognitive skills. Expert judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' higher order thinking skills (HOTS), as seen by a 75% (large effect) increase in response to the model's application. Changes in student behavior and character that appeared during the application of the MiSHE learning model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation.

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Commented [A31]: many old references found

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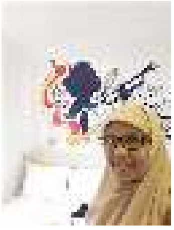

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Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' HOTS. The ADDIE (analyze, design, develop, implement, and evaluate) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. Expert validation was conducted with seven educational experts using the Delphi technique. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. The model's construct validity was evaluated using randomly selected classrooms from two different institutions, while the model's content validity was checked using the Aiken's V formula (content-validity coefficient (V)). In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a General Linear Model and Multivariate Analysis of Variance (MANOVA), followed by an effect size analysis utilizing Cohen's d to ascertain the model's effect on students' HOTS. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers. Based on the results of a preliminary study on 21 primary school teacher education programs in Indonesia, science education is offered through courses that emphasize science content and science learning development. These courses are geared toward increasing technological pedagogical content knowledge (TPACK). If the students' science content is good, it will have a positive impact on their TPACK. Therefore, content knowledge can support the realization of TPACK [1], [2]. Graduates of the primary school teacher education department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the PSTE department should also develop higher-order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [3], face difficulty learning science (Maryani, Husna, Wangid, Mustadi, & Vahechart, 2018), and have poor performance in science.

In addition, the occurrence of the Covid-19 Pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision-making skills, and thinking skills, which are also known as 21st-century skills.

The twenty-first-century skills have become a topic of discussion among several educational institutions, practitioners, and experts. According to Trisdiono (2013), the 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills. In addition, ATC21S (Assessment & Teaching of 21st Century Skills) classifies 21st-century skills into four areas; one of which is methods of thinking [6]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS (High-order Thinking Skills).

The lecturers continue to struggle with teaching HOTS and preparing their students to use higher-order thinking in everyday life. Learning that continues to emphasize the development of lower-level thinking skills (LOTS) contributes to the poor higher order thinking skills (HOTS) of teachers in Indonesia [7]. This could be due to the instructors' lack of expertise regarding how to hone students' higher-order thinking skills [8]. According to studies [9], [10], the LOTS group contains a greater number of future primary school teachers students than the HOTS category. Therefore, a learning model in higher education is needed that empowers HOTS by involving students mentally and cognitively in every learning process.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting higher-order thinking skills (HOTS) in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as PBL [11], RMS (Reading, Mapping, and Sharing) [12], CUPs (Conceptual Understanding Procedures) [13], Constructive Conflict (CC), and Modified Free Inquiry (MFI) [14], FILM [15], and Guided Inquiry Laboratory-Based Module (GILM [16] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: 1) help students monitor their progress and control their learning process (through reading, writing, solving problems); 2) contribute to students' learning desire above their intellectual abilities [17], [18]; 3) improve academic achievement across age, cognitive abilities, and learning domains [19], [20]; and 4) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities such as 1) reflecting on the thought processes involved in the learning process; 2) seeking concrete examples from prior learning experiences and mindsets; 3) analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; 4) making generalizations and formulating rules about these thought patterns; and 5) naming the thought pattern [21]–[23]. This integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously.

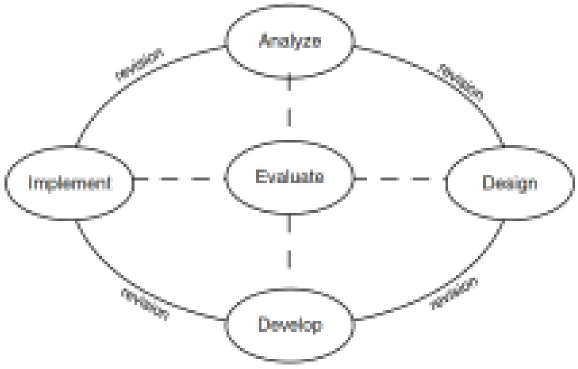
Research Questions

1. What role does metacognition play in an online learning model?

2. To what extent is metacognition-integrated online learning effective in promoting students' higher-order thinking skills (HOTS) in science?

2. METHODS

The current R&D study used the ADDIE (Analysis, Design, Develop, Implement, dan Evaluate) model [24] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.



Source: [24]

Figure 1. The ADDIE procedure

The urgency of developing the learning model as well as problem analysis was carried out at the *Analyze* stage. A needs analysis was conducted through depth interviews. Depth interview telah dilaksanakan pada pertemuan dosen IPA PGSD dan melibatkan 21 science lecturers from primary school teacher education departments in 7 state universities and 14 private universities in Indonesia. The results of the need assessment show that 1) the variability of the educational background of primary school teacher education’s students causes the interest and speed in understanding science material to vary, 2) the selection of learning models becomes difficult because of this diversity factor, 3) students' creativity is still lacking so that their ability to develop ideas is not optimal, 4) mastery practice and presentation skills are still lacking, 5) reading interest is lacking so that their ability to understand concepts is still low and even has the potential for misconceptions, and 6) students' understanding is still at cognitive level 1 (memorization) so it needs to be encouraged to reach a higher level.

At the *Design* stage, the product’s design and draft were created. At the *Develop* stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both contents (expert judgment) and construct (experimental study). Content validity is carried out to determine the feasibility of the learning model based on expert judgment [25]. Construct validity was carried out to determine the effectiveness of the learning model towards increasing HOTS [26], [27]. The process of implementing the learning model on a wider scale is carried out at the *Implement* stage. Content validation with the Delphi technique involved 7 experts. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. While the construct validity was conducted to test the effectiveness of the model through an experimental study by randomized Pretest-Posttest Comparison Group Design. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan, Yogyakarta, Indonesia, and Universitas Sarjanawiyata Tamansiswa, Yogyakarta, Indonesia. The effectiveness test involved three homogeneous groups to determine the robustness of the metacognitive integrative model. The experimental group was compared with two control groups who were given the model treatment commonly used by lecturers, namely problem-based learning (control 1) and experiment (control 2). The study involved 41 students as the experimental group, 39 students as the control group 1, and 39 students as the control group 2.

Evaluation is carried out at the process stage and the end of the activity, namely from the analysis, design, development, and implementation stages. The evaluation stage in this study uses formative and summative because it is related to the application of new learning models. The goal is to determine whether the objectives of the model are met and determine what is needed to increase the effectiveness of the model. After the implementation of the model is complete, a summative evaluation is carried out to determine the impact of implementing the model on learning. During the evaluation phase, problems that occur during data learning are identified and resolved and research objectives must also be achieved. The evaluation that will be used in this study refers to the Kirkpatrick evaluation model [28]

Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The following equation represents the content-validity coefficient (V):

$$\mathbf{V} = \frac{\sum \mathbf{s}}{[\mathbf{n}(\mathbf{c}-\mathbf{1})]} \quad \mathbf{(1)}$$

Remarks:

Io	= the lowest validity score (in this case = 1)
c	= the highest validity score (in this case = 5)
r	= expert judgment score
s	= r – Io
c	= number of experts
V	= content-validity coefficient (between 0-1) [29]

To determine the effect of metacognition integration in online science learning on students' HOTS, analysis of General Linear Model and Multivariate Analysis of Variance (Manova). MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the Effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [30]–[32].

3. RESULT AND DISCUSSION

3.1. Result

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education programs at seven public universities and fourteen private universities in Indonesia revealed that the students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of the material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement (Maryani et al., 2021).

The design of the metacognition-integrated science learning model produced in the *Design* stage is shown in Figure 2. The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' higher-order thinking skills (HOTS). The lesson plan comprises 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, Learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project.

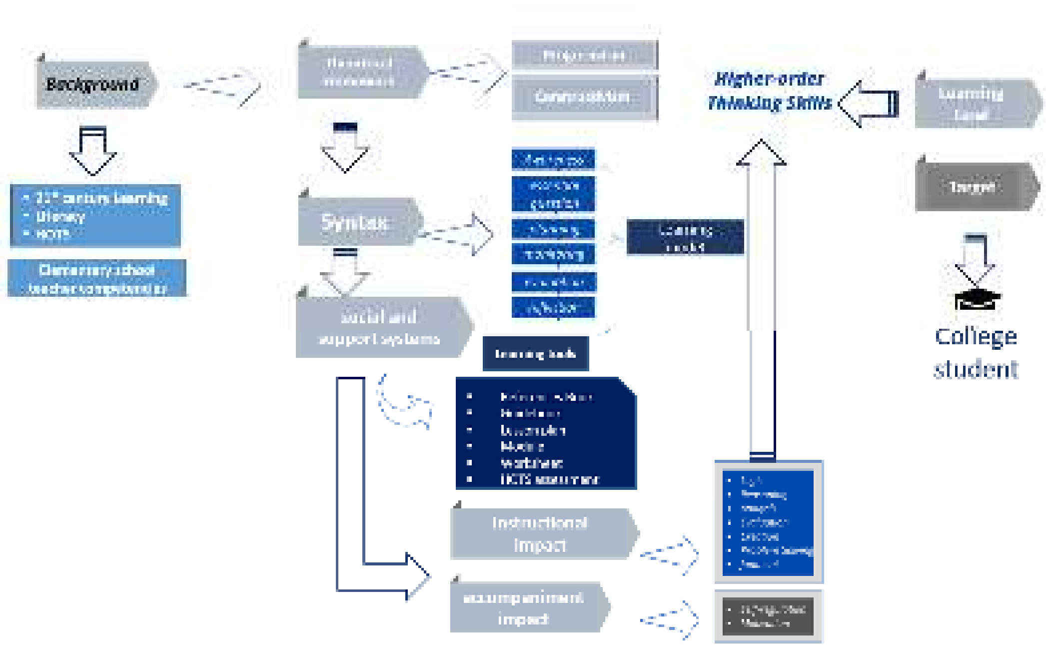


Figure 2. Online science learning model integrated metacognition

The *Develop* Stage generated the data on the model's content and construct validity test results.

Table 1. Expert Judgement on the Model's Content Validity

Product	Aspect	V-Score	Criteria
The Model's Book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language Use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language Use	0.911	Valid (high)
RPS		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the PhET simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to [34] criteria for practicality, the learning model was implemented successfully for the students that participated in this study.

To investigate the extent of the treatment impact, hypotheses were tested using the General Linear Model (GLM) and Multivariate of Variance (MANOVA). Four assumptions must be met for this test to be valid: 1) an independent observer, 2) a random sample, and 3) normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (< 0.05). In an experimental study, the error factor (subject, sample, treatment, etc.) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [35]. (Blanca et al., (2017) confirm this point by stating that the uniformity of data in an experiment can be overlooked. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [37].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by Tests of Within-Subjects Effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the Mean Different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14,923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS (Table 2).

Table 2. Multivariate Tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
experiment	Pillai's trace	,745	45,419[a]	7,000	109,000	,000	,745
	Wilks' lambda	,255	45,419[a]	7,000	109,000	,000	,745
	Hotelling's trace	2,917	45,419[a]	7,000	109,000	,000	,745
	Roy's largest root	2,917	45,419[a]	7,000	109,000	,000	,745
Control 1	Pillai's trace	,354	8,530[a]	7,000	109,000	,000	,354
	Wilks' lambda	,646	8,530[a]	7,000	109,000	,000	,354
	Hotelling's trace	,548	8,530[a]	7,000	109,000	,000	,354
	Roy's largest root	,548	8,530[a]	7,000	109,000	,000	,354
Control 2	Pillai's trace	,684	33,638[a]	7,000	109,000	,000	,684
	Wilks' lambda	,316	33,638[a]	7,000	109,000	,000	,684
	Hotelling's trace	2,160	33,638[a]	7,000	109,000	,000	,684
	Roy's largest root	2,160	33,638[a]	7,000	109,000	,000	,684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column as suggested by Leech et al (2013). A partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. Based on Bakker et al., (2019), Cohen (1988), dan Mordkoff (2019), the value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5). The effect size of the metacognition integrated learning model on students' HOTS was quite large because it was more than 50%. The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

3.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' higher-order thinking skills (HOTS) to solve problems and make sound decisions in their life after graduation. Higher-order thinking skills (HOTS) are inextricably linked to technological, pedagogical, and content knowledge (TPACK) [39], [40]. These abilities are critical for developing students' problem-solving abilities [41]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [42], which is especially critical in elementary school science instruction.

Syntax of the learning model established in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: 1) awareness of knowledge/person factors, 2) awareness of thought/task variables, and 3) awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [43]. These three elements are represented in the learning model's *awareness* step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [44].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [21]–[23]. Planning, monitoring, and assessing are all components of metacognition [45]. The three are then included in the learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, Phet, and sound meter software, as well as video presentation projects, are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness) concerning the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' higher-order thinking skills (HOTS) in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occurring around them [46]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mind-mapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [47], [48]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems (Özreçberoğlu & Çağsanağa, 2018).

The advantages of the metacognition-integrated learning model are as follows: (1) the model was developed using scientific procedures that are quantifiable and involve experts; (2) the model can be implemented in normal or pandemic conditions by adjusting the learning activities; 3) the learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; 4) the learning model was designed based on real-world situations; 5) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

4. Conclusion

This research contributes to the development of science in the form of an innovative science learning model integrated with metacognition strategies. Metacognition can be integrated into online science learning through awareness, essential questions, planning, monitoring, evaluating, and reflecting. The lesson plans and teaching materials were developed regarding this syntax via instructional activities that strengthen metacognitive skills. The expert's judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' higher-order thinking skills (HOTS), as seen by a 75% (large effect) increase in response to the model's implementation. Changes in student behavior and character that appeared during the application of the model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation. The limitation of this study is that the effect of this model has only been measured on the HOTS variable in total, further analysis has not been carried out on the HOTS aspects separately (logic, reasoning, analysis, evaluation, creation, problem-solving, and judgment). Changes in behavior and character that appear during the application of this learning model are very diverse, but researchers only limit them to HOTS. Other characters have not been observed.

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Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' HOTS. The ADDIE (analyze, design, develop, implement, and evaluate) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. Expert validation was conducted with seven educational experts using the Delphi technique. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. The model's construct validity was evaluated using randomly selected classrooms from two different institutions, while the model's content validity was checked using the Aiken's V formula (content-validity coefficient (V)). In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a General Linear Model and Multivariate Analysis of Variance (MANOVA), followed by an effect size analysis utilizing Cohen's d to ascertain the model's effect on students' HOTS. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers. Based on the results of a preliminary study on 21 primary school teacher education programs in Indonesia, science education is offered through courses that emphasize science content and science learning development. These courses are geared toward increasing technological pedagogical content knowledge (TPACK). If the students' science content is good, it will have a

positive impact on their TPACK. Therefore, content knowledge can support the realization of TPACK [1], [2]. Graduates of the primary school teacher education department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the PSTE department should also develop higher-order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [3], face difficulty learning science [4], and have poor performance in science.

In addition, the occurrence of the Covid-19 Pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision-making skills, and thinking skills, which are also known as 21st-century skills.

The twenty-first-century skills have become a topic of discussion among several educational institutions, practitioners, and experts. The 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills [5]. In addition, ATC21S (Assessment & Teaching of 21st Century Skills) classifies 21st-century skills into four areas; one of which is methods of thinking [6]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS (High-order Thinking Skills).

The lecturers continue to struggle with teaching HOTS and preparing their students to use higher-order thinking in everyday life. Learning that continues to emphasize the development of lower-level thinking skills (LOTS) contributes to the poor higher-order thinking skills (HOTS) of teachers in Indonesia [7]. This could be due to the instructors' lack of expertise regarding how to hone students' higher-order thinking skills [8]. According to studies [9], [10], the LOTS group contains a greater number of future primary school teachers students than the HOTS category. Therefore, a learning model in higher education is needed that empowers HOTS by involving students mentally and cognitively in every learning process.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting higher-order thinking skills (HOTS) in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as PBL [11], RMS (Reading, Mapping, and Sharing) [12], CUPs (Conceptual Understanding Procedures) [13], Constructive Conflict (CC), and Modified Free Inquiry (MFI) [14], FILM [15], and Guided Inquiry Laboratory-Based Module (GILM [16] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: 1) help students monitor their progress and control their learning process (through reading, writing, solving problems); 2) contribute to students' learning desire above their intellectual abilities [17], [18]; 3) improve academic achievement across age, cognitive abilities, and learning domains [19], [20]; and 4) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities such as 1) reflecting on the thought processes involved in the learning process; 2) seeking concrete examples from prior learning experiences and mindsets; 3) analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; 4) making generalizations and formulating rules about these thought patterns; and 5) naming the thought pattern [21]–[23]. This integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously.

Research Questions

1. What role does metacognition play in an online learning model?
2. To what extent is metacognition-integrated online learning effective in promoting students' higher-order thinking skills (HOTS) in science?

2. METHODS

The current R&D study used the ADDIE (Analysis, Design, Develop, Implement, dan Evaluate) model [24] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.

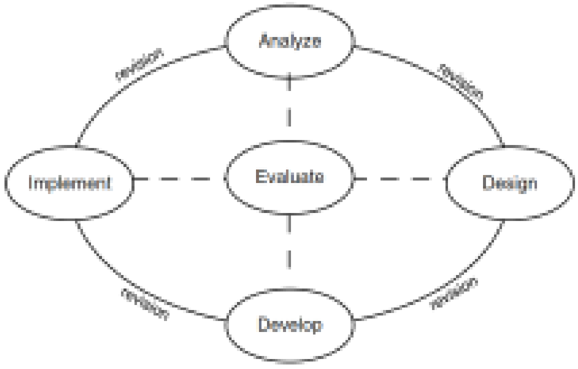

Figure 1. The ADDIE procedure

The urgency of developing the learning model as well as problem analysis was carried out at the *Analyze* stage. A needs analysis was conducted through depth interviews. Depth interview telah dilaksanakan pada pertemuan dosen IPA PGSD dan melibatkan 21 science lecturers from primary school teacher education departments in 7 state universities and 14 private universities in Indonesia. The results of the need assessment show that 1) the variability of the educational background of primary school teacher education's students causes the interest and speed in understanding science material to vary, 2) the selection of learning models becomes difficult because of this diversity factor, 3) students' creativity is still lacking so that their ability to develop ideas is not optimal, 4) mastery practice and presentation skills are still lacking, 5) reading interest is lacking so that their ability to understand concepts is still low and even has the potential for misconceptions, and 6) students' understanding is still at cognitive level 1 (memorization) so it needs to be encouraged to reach a higher level.

At the *Design* stage, the product's design and draft were created. At the *Develop* stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both contents (expert judgment) and construct (experimental study). Content validity is carried out to determine the feasibility of the learning model based on expert judgment [25]. Construct validity was carried out to determine the effectiveness of the learning model towards increasing HOTS [26], [27]. The process of implementing the learning model on a wider scale is carried out at the *Implement* stage. Content validation with the Delphi technique involved 7 experts. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. While the construct validity was conducted to test the effectiveness of the model through an experimental study by randomized Pretest-Posttest Comparison Group Design. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan, Yogyakarta, Indonesia, and Universitas Sarjanawiyata Tamansiswa, Yogyakarta, Indonesia. The effectiveness test involved three homogeneous groups to determine the robustness of the metacognitive integrative model. The experimental group was compared with two control groups who were given the model treatment commonly used by lecturers, namely problem-based learning (control 1) and experiment (control 2). The study involved 41 students as the experimental group, 39 students as the control group 1, and 39 students as the control group 2.

Evaluation is carried out at the process stage and the end of the activity, namely from the analysis, design, development, and implementation stages. The evaluation stage in this study uses formative and summative because it is related to the application of new learning models. The goal is to determine whether the objectives of the model are met and determine what is needed to increase the effectiveness of the model. After the implementation of the model is complete, a summative evaluation is carried out to determine the impact of implementing the model on learning. During the evaluation phase, problems that occur during data learning are identified and resolved and research objectives must also be achieved. The evaluation that will be used in this study refers to the Kirkpatrick evaluation model [28]

Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The following equation represents the content-validity coefficient (V):

$$V = \frac{\sum s}{[n(c-1)]} \quad (1)$$

Remarks:
Io = the lowest validity score (in this case = 1)
c = the highest validity score (in this case = 5)
r = expert judgment score
s = r – Io
c = number of experts
V = content-validity coefficient (between 0-1) [29]

To determine the effect of metacognition integration in online science learning on students' HOTS, analysis of General Linear Model and Multivariate Analysis of Variance. MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the Effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [30]–[32].

3. RESULT AND DISCUSSION

3.1. Result

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education programs at seven public universities and fourteen private universities in Indonesia revealed that the students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of the material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement.

The design of the metacognition-integrated science learning model produced in the *Design* stage is shown in Figure 2. The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' higher-order thinking skills (HOTS). The lesson plan comprises 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, Learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project.

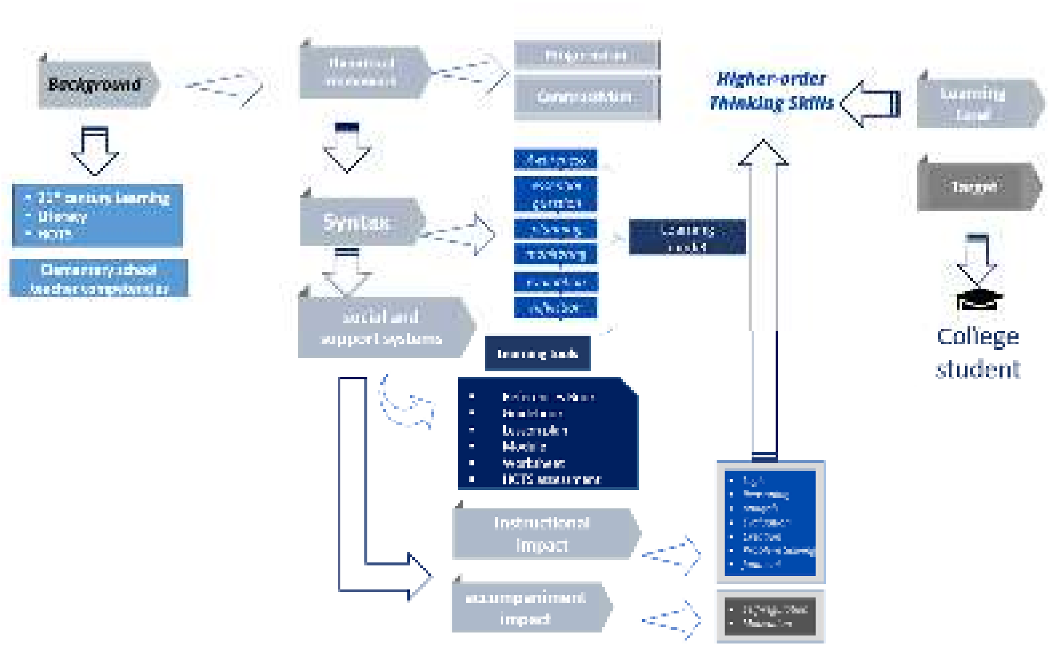

Figure 2. Online science learning model integrated metacognition

The *Develop* Stage generated the data on the model's content and construct validity test results.

Table 1. Expert Judgement on the Model's Content Validity

Product	Aspect	V-Score	Criteria
The Model's Book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language Use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language Use	0.911	Valid (high)
RPS		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the PhET simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to [33] criteria for practicality, the learning model was implemented successfully for the students that participated in this study.

To investigate the extent of the treatment impact, hypotheses were tested using the General Linear Model (GLM) and Multivariate of Variance (MANOVA). Four assumptions must be met for this test to be valid: 1) an independent observer, 2) a random sample, and 3) normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (< 0.05). In an experimental study, the error factor (subject, sample, treatment, etc.) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [34]. The uniformity of data in an experiment can be overlooked [35]. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [36].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by Tests of Within-Subjects Effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the Mean Different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14,923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS (Table 2).

Table 2. Multivariate Tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
experiment	Pillai's trace	,745	45,419ª	7,000	109,000	,000	,745
	Wilks' lambda	,255	45,419ª	7,000	109,000	,000	,745
	Hotelling's trace	2,917	45,419ª	7,000	109,000	,000	,745
	Roy's largest root	2,917	45,419ª	7,000	109,000	,000	,745
Control 1	Pillai's trace	,354	8,530ª	7,000	109,000	,000	,354
	Wilks' lambda	,646	8,530ª	7,000	109,000	,000	,354
	Hotelling's trace	,548	8,530ª	7,000	109,000	,000	,354
	Roy's largest root	,548	8,530ª	7,000	109,000	,000	,354
Control 2	Pillai's trace	,684	33,638ª	7,000	109,000	,000	,684
	Wilks' lambda	,316	33,638ª	7,000	109,000	,000	,684
	Hotelling's trace	2,160	33,638ª	7,000	109,000	,000	,684
	Roy's largest root	2,160	33,638ª	7,000	109,000	,000	,684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column [37]. A partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. The value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5) [30]–[32]. The effect size of the metacognition integrated learning model on students' HOTS was quite large because it was more than 50%. The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

3.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' higher-order thinking skills (HOTS) to solve problems and make sound decisions in their life after graduation. Higher-order thinking skills (HOTS) are inextricably linked to technological, pedagogical, and content knowledge (TPACK) [38], [39]. These abilities are critical for developing students' problem-solving abilities [40]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [41], which is especially critical in elementary school science instruction.

Syntax of the learning model established in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: 1) awareness of knowledge/person factors, 2) awareness of thought/task variables, and 3) awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [42]. These three elements are represented in the learning model's *awareness* step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [43].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [21]–[23]. Planning, monitoring, and assessing are all components of metacognition [44]. The three are then included in the learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, PhET, and sound meter software, as well as video presentation projects, are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness) concerning the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' higher-order thinking skills (HOTS) in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occurring around them [45]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mind-mapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [46], [47]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems [48].

The advantages of the metacognition-integrated learning model are as follows: (1) the model was developed using scientific procedures that are quantifiable and involve experts; (2) the model can be implemented in normal or pandemic conditions by adjusting the learning activities; 3) the learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; 4) the learning model was designed based on real-world situations; 5) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

4. Conclusion

This research contributes to the development of science in the form of an innovative science learning model integrated with metacognition strategies. Metacognition can be integrated into online science learning through awareness, essential questions, planning, monitoring, evaluating, and reflecting. The lesson plans and teaching materials were developed regarding this syntax via instructional activities that strengthen metacognitive skills. The expert's judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' higher-order thinking skills (HOTS), as seen by a 75% (large effect) increase in response to the model's implementation. Changes in student behavior and character that appeared during the application of the model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation. The limitation of this study is that the effect of this model has only been measured on the HOTS variable in total, further analysis has not been carried out on the HOTS aspects separately (logic, reasoning, analysis, evaluation, creation, problem-solving, and judgment). Changes in behavior and character that appear during the application of this learning model are very diverse, but researchers only limit them to HOTS. Other characters have not been observed.

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Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' HOTS. The ADDIE (analyze, design, develop, implement, and evaluate) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. Expert validation was conducted with seven educational experts using the Delphi technique. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. The model's construct validity was evaluated using randomly selected classrooms from two different institutions, while the model's content validity was checked using the Aiken's V formula (content-validity coefficient (V)). In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a General Linear Model and Multivariate Analysis of Variance (MANOVA), followed by an effect size analysis utilizing Cohen's d to ascertain the model's effect on students' HOTS. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers. Based on the results of a preliminary study on 21 primary school teacher education programs in Indonesia, science education is offered through courses that emphasize science content and science learning development. These courses are geared toward increasing technological pedagogical content knowledge (TPACK). If the students' science content is good, it will have a

positive impact on their TPACK. Therefore, content knowledge can support the realization of TPACK [1], [2]. Graduates of the primary school teacher education department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the PSTE department should also develop higher-order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [3], face difficulty learning science [4], and have poor performance in science.

In addition, the occurrence of the Covid-19 Pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision-making skills, and thinking skills, which are also known as 21st-century skills.

The twenty-first-century skills have become a topic of discussion among several educational institutions, practitioners, and experts. The 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills [5]. In addition, ATC21S (Assessment & Teaching of 21st Century Skills) classifies 21st-century skills into four areas; one of which is methods of thinking [6]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS (High-order Thinking Skills).

The lecturers continue to struggle with teaching HOTS and preparing their students to use higher-order thinking in everyday life. Learning that continues to emphasize the development of lower-level thinking skills (LOTS) contributes to the poor higher-order thinking skills (HOTS) of teachers in Indonesia [7]. This could be due to the instructors' lack of expertise regarding how to hone students' higher-order thinking skills [8]. According to studies [9], [10], the LOTS group contains a greater number of future primary school teachers students than the HOTS category. Therefore, a learning model in higher education is needed that empowers HOTS by involving students mentally and cognitively in every learning process.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting higher-order thinking skills (HOTS) in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as PBL [11], RMS (Reading, Mapping, and Sharing) [12], CUPs (Conceptual Understanding Procedures) [13], Constructive Conflict (CC), and Modified Free Inquiry (MFI) [14], FILM [15], and Guided Inquiry Laboratory-Based Module (GILM [16] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: 1) help students monitor their progress and control their learning process (through reading, writing, solving problems); 2) contribute to students' learning desire above their intellectual abilities [17], [18]; 3) improve academic achievement across age, cognitive abilities, and learning domains [19], [20]; and 4) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities such as 1) reflecting on the thought processes involved in the learning process; 2) seeking concrete examples from prior learning experiences and mindsets; 3) analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; 4) making generalizations and formulating rules about these thought patterns; and 5) naming the thought pattern [21]–[23]. This integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously.

Research Questions

1. What role does metacognition play in an online learning model?
2. To what extent is metacognition-integrated online learning effective in promoting students' higher-order thinking skills (HOTS) in science?

2. METHODS

The current R&D study used the ADDIE (Analysis, Design, Develop, Implement, dan Evaluate) model [24] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.

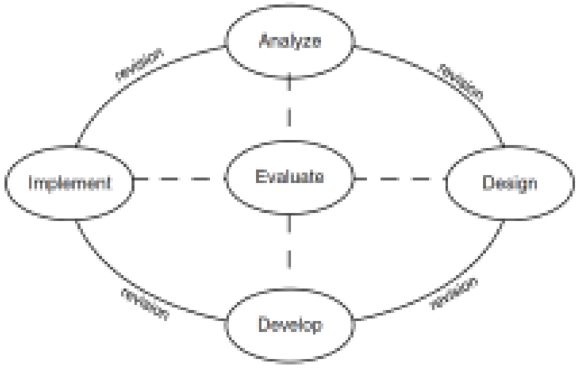

Figure 1. The ADDIE procedure

The urgency of developing the learning model as well as problem analysis was carried out at the *Analyze* stage. A needs analysis was conducted through depth interviews. The depth interview has been carried out by involving 21 science lecturers in the elementary school teacher education department 7 state universities and 14 private universities in Indonesia. The results of the need assessment show that 1) the variability of the educational background of primary school teacher education's students causes the interest and speed in understanding science material to vary, 2) the selection of learning models becomes difficult because of this diversity factor, 3) students' creativity is still lacking so that their ability to develop ideas is not optimal, 4) mastery practice and presentation skills are still lacking, 5) reading interest is lacking so that their ability to understand concepts is still low and even has the potential for misconceptions, and 6) students' understanding is still at cognitive level 1 (memorization) so it needs to be encouraged to reach a higher level.

At the *Design* stage, the product's design and draft were created. At the *Develop* stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both contents (expert judgment) and construct (experimental study). Content validity is carried out to determine the feasibility of the learning model based on expert judgment [25]. Construct validity was carried out to determine the effectiveness of the learning model towards increasing HOTS [26], [27]. The process of implementing the learning model on a wider scale is carried out at the *Implement* stage. Content validation with the Delphi technique involved 7 experts. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. While the construct validity was conducted to test the effectiveness of the model through an experimental study by randomized Pretest-Posttest Comparison Group Design. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan, Yogyakarta, Indonesia, and Universitas Sarjanawiyata Tamansiswa, Yogyakarta, Indonesia. The effectiveness test involved three homogeneous groups to determine the robustness of the metacognitive integrative model. The experimental group was compared with two control groups who were given the model treatment commonly used by lecturers, namely problem-based learning (control 1) and experiment (control 2). The study involved 41 students as the experimental group, 39 students as the control group 1, and 39 students as the control group 2.

Evaluation is carried out at the process stage and the end of the activity, namely from the analysis, design, development, and implementation stages. The evaluation stage in this study uses formative and summative because it is related to the application of new learning models. The goal is to determine whether the objectives of the model are met and determine what is needed to increase the effectiveness of the model. After the implementation of the model is complete, a summative evaluation is carried out to determine the impact of implementing the model on learning. During the evaluation phase, problems that occur during data learning are identified and resolved and research objectives must also be achieved. The evaluation that will be used in this study refers to the Kirkpatrick evaluation model [28]

Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The following equation represents the content-validity coefficient (V):

$$\mathbf{V} = \frac{\sum \mathbf{s}}{[\mathbf{n}(\mathbf{c}-\mathbf{1})]} \quad (1)$$

Remarks:
Io = the lowest validity score (in this case = 1)
c = the highest validity score (in this case = 5)
r = expert judgment score
s = r – Io
c = number of experts
V = content-validity coefficient (between 0-1)[29]

To determine the effect of metacognition integration in online science learning on students' HOTS, analysis of General Linear Model and Multivariate Analysis of Variance. MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the Effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [30]–[32].

3. RESULT AND DISCUSSION

3.1. Result

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education programs at seven public universities and fourteen private universities in Indonesia revealed that the students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of the material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement.

The design of the metacognition-integrated science learning model produced in the *Design* stage is shown in Figure 2. The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' higher-order thinking skills (HOTS). The lesson plan comprises 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, Learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project.

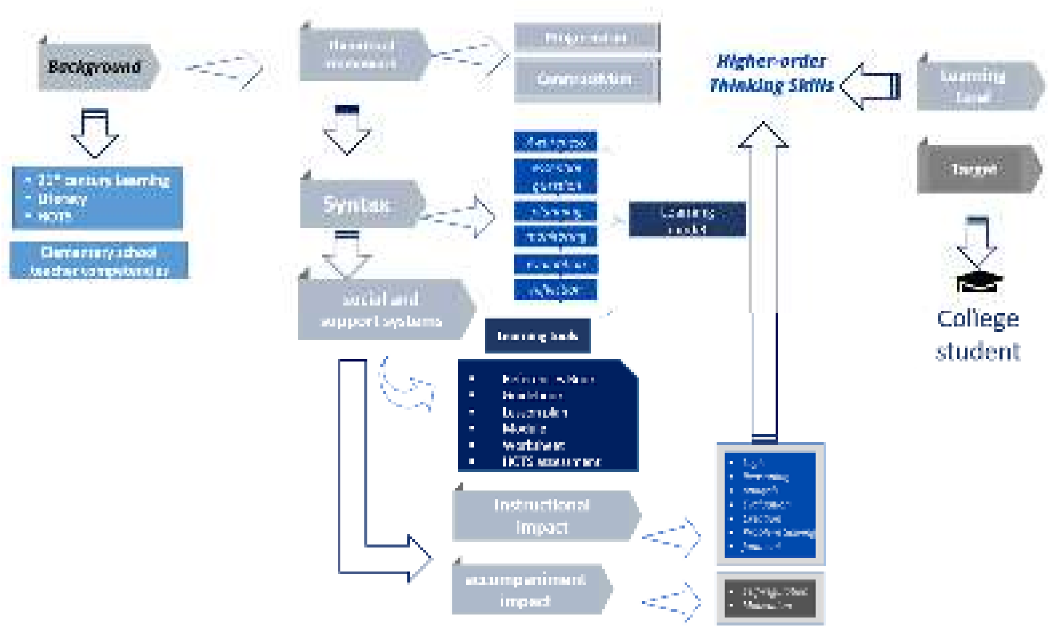

Figure 2. Online science learning model integrated metacognition

The *Develop* Stage generated the data on the model's content and construct validity test results.

Table 1. Expert Judgement on the Model's Content Validity

Product	Aspect	V-Score	Criteria
The Model's Book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language Use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language Use	0.911	Valid (high)
Lesson plan		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the PhET simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to [33] criteria for practicality, the learning model was implemented successfully for the students that participated in this study.

To investigate the extent of the treatment impact, hypotheses were tested using the General Linear Model (GLM) and Multivariate of Variance (MANOVA). Four assumptions must be met for this test to be valid: 1) an independent observer, 2) a random sample, and 3) normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (< 0.05). In an experimental study, the error factor (subject, sample, treatment, etc.) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [34]. The uniformity of data in an experiment can be overlooked [35]. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [36].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by Tests of Within-Subjects Effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the Mean Different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14.923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS (Table 2).

Table 2. Multivariate Tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
experiment	Pillai's trace	.745	45.419[a]	7.000	109.000	.000	.745
	Wilks' lambda	.255	45.419[a]	7.000	109.000	.000	.745
	Hotelling's trace	2.917	45.419[a]	7.000	109.000	.000	.745
	Roy's largest root	2.917	45.419[a]	7.000	109.000	.000	.745
Control 1	Pillai's trace	.354	8.530[a]	7.000	109.000	.000	.354
	Wilks' lambda	.646	8.530[a]	7.000	109.000	.000	.354
	Hotelling's trace	.548	8.530[a]	7.000	109.000	.000	.354
	Roy's largest root	.548	8.530[a]	7.000	109.000	.000	.354
Control 2	Pillai's trace	.684	33.638[a]	7.000	109.000	.000	.684
	Wilks' lambda	.316	33.638[a]	7.000	109.000	.000	.684
	Hotelling's trace	2.160	33.638[a]	7.000	109.000	.000	.684
	Roy's largest root	2.160	33.638[a]	7.000	109.000	.000	.684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column [37]. A partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. The value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5) [30]–[32]. The effect size of the metacognition integrated learning model on students' HOTS was quite large because it was more than 50%. The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

3.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' higher-order thinking skills (HOTS) to solve problems and make sound decisions in their life after graduation. Higher-order thinking skills (HOTS) are inextricably linked to technological, pedagogical, and content knowledge (TPACK) [38], [39]. These abilities are critical for developing students' problem-solving abilities [40]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [41], which is especially critical in elementary school science instruction.

Syntax of the learning model established in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: 1) awareness of knowledge/person factors, 2) awareness of thought/task variables, and 3) awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [42]. These three elements are represented in the learning model's *awareness* step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [43].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [21]–[23]. Planning, monitoring, and assessing are all components of metacognition [44]. The three are then included in the learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, PhET, and sound meter software, as well as video presentation projects, are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness) concerning the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' higher-order thinking skills (HOTS) in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occurring around them [45]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mind-mapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [46], [47]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems [48].

The advantages of the metacognition-integrated learning model are as follows: (1) the model was developed using scientific procedures that are quantifiable and involve experts; (2) the model can be implemented in normal or pandemic conditions by adjusting the learning activities; 3) the learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; 4) the learning model was designed based on real-world situations; 5) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

4. Conclusion

This research contributes to the development of science in the form of an innovative science learning model integrated with metacognition strategies. Metacognition can be integrated into online science learning through awareness, essential questions, planning, monitoring, evaluating, and reflecting. The lesson plans and teaching materials were developed regarding this syntax via instructional activities that strengthen metacognitive skills. The expert's judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' higher-order thinking skills (HOTS), as seen by a 75% (large effect) increase in response to the model's implementation. Changes in student behavior and character that appeared during the application of the model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation. The limitation of this study is that the effect of this model has only been measured on the HOTS variable in total, further analysis has not been carried out on the HOTS aspects separately (logic, reasoning, analysis, evaluation, creation, problem-solving, and judgment). Changes in behavior and character that appear during the application of this learning model are very diverse, but researchers only limit them to HOTS. Other characters have not been observed.

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Promoting Higher-order Thinking Skills (HOTS) during Online Learning: The Integration of Metacognition in Science for Higher Education

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' HOTS. The ADDIE (analyze, design, develop, implement, and evaluate) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. Expert validation was conducted with seven educational experts using the Delphi technique. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. The model's construct validity was evaluated using randomly selected classrooms from two different institutions, while the model's content validity was checked using the Aiken's V formula (content-validity coefficient (V)). In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a General Linear Model and Multivariate Analysis of Variance (MANOVA), followed by an effect size analysis utilizing Cohen's d to ascertain the model's effect on students' HOTS. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers. Based on the results of a preliminary study on 21 primary school teacher education programs in Indonesia, science education is offered through courses that emphasize science content and science learning development. These courses are geared toward increasing technological pedagogical content knowledge (TPACK). If the students' science content is good, it will have a

positive impact on their TPACK. Therefore, content knowledge can support the realization of TPACK [1], [2]. Graduates of the primary school teacher education department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the PSTE department should also develop higher-order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [3], face difficulty learning science [4], and have poor performance in science.

In addition, the occurrence of the Covid-19 Pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision-making skills, and thinking skills, which are also known as 21st-century skills.

The twenty-first-century skills have become a topic of discussion among several educational institutions, practitioners, and experts. The 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills [5]. In addition, ATC21S (Assessment & Teaching of 21st Century Skills) classifies 21st-century skills into four areas; one of which is methods of thinking [6]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS (High-order Thinking Skills).

The lecturers continue to struggle with teaching HOTS and preparing their students to use higher-order thinking in everyday life. Learning that continues to emphasize the development of lower-level thinking skills (LOTS) contributes to the poor higher-order thinking skills (HOTS) of teachers in Indonesia [7]. This could be due to the instructors' lack of expertise regarding how to hone students' higher-order thinking skills [8]. According to studies [9], [10], the LOTS group contains a greater number of future primary school teachers students than the HOTS category. Therefore, a learning model in higher education is needed that empowers HOTS by involving students mentally and cognitively in every learning process.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting higher-order thinking skills (HOTS) in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as PBL [11], RMS (Reading, Mapping, and Sharing) [12], CUPs (Conceptual Understanding Procedures) [13], Constructive Conflict (CC), and Modified Free Inquiry (MFI) [14], FILM [15], and Guided Inquiry Laboratory-Based Module (GILM [16] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: 1) help students monitor their progress and control their learning process (through reading, writing, solving problems); 2) contribute to students' learning desire above their intellectual abilities [17], [18]; 3) improve academic achievement across age, cognitive abilities, and learning domains [19], [20]; and 4) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities such as 1) reflecting on the thought processes involved in the learning process; 2) seeking concrete examples from prior learning experiences and mindsets; 3) analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; 4) making generalizations and formulating rules about these thought patterns; and 5) naming the thought pattern [21]–[23]. This integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously.

Research Questions

1. What role does metacognition play in an online learning model?
2. To what extent is metacognition-integrated online learning effective in promoting students' higher-order thinking skills (HOTS) in science?

2. RESEARCH METHODS

The current R&D study used the ADDIE (Analysis, Design, Develop, Implement, dan Evaluate) model [24] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.

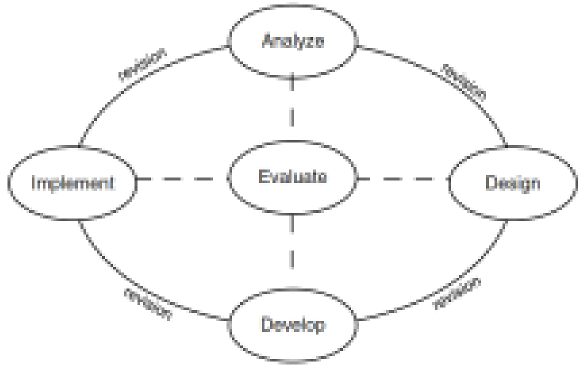

Figure 1. The ADDIE procedure

The urgency of developing the learning model as well as problem analysis was carried out at the *Analyze* stage. A needs analysis was conducted through depth interviews. The depth interview has been carried out by involving 21 science lecturers in the elementary school teacher education department 7 state universities and 14 private universities in Indonesia. The results of the need assessment show that 1) the variability of the educational background of primary school teacher education's students causes the interest and speed in understanding science material to vary, 2) the selection of learning models becomes difficult because of this diversity factor, 3) students' creativity is still lacking so that their ability to develop ideas is not optimal, 4) mastery practice and presentation skills are still lacking, 5) reading interest is lacking so that their ability to understand concepts is still low and even has the potential for misconceptions, and 6) students' understanding is still at cognitive level 1 (memorization) so it needs to be encouraged to reach a higher level.

At the *Design* stage, the product's design and draft were created. At the *Develop* stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both contents (expert judgment) and construct (experimental study). Content validity is carried out to determine the feasibility of the learning model based on expert judgment [25]. Construct validity was carried out to determine the effectiveness of the learning model towards increasing HOTS [26], [27]. The process of implementing the learning model on a wider scale is carried out at the *Implement* stage. Content validation with the Delphi technique involved 7 experts. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and 2 science lecturers from the elementary school teacher education study program. While the construct validity was conducted to test the effectiveness of the model through an experimental study by randomized Pretest-Posttest Comparison Group Design. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan, Yogyakarta, Indonesia, and Universitas Sarjanawiyata Tamansiswa, Yogyakarta, Indonesia. The effectiveness test involved three homogeneous groups to determine the robustness of the metacognitive integrative model. The experimental group was compared with two control groups who were given the model treatment commonly used by lecturers, namely problem-based learning (control 1) and experiment (control 2). The study involved 41 students as the experimental group, 39 students as the control group 1, and 39 students as the control group 2.

Evaluation is carried out at the process stage and the end of the activity, namely from the analysis, design, development, and implementation stages. The evaluation stage in this study uses formative and summative because it is related to the application of new learning models. The goal is to determine whether the objectives of the model are met and determine what is needed to increase the effectiveness of the model. After the implementation of the model is complete, a summative evaluation is carried out to determine the impact of implementing the model on learning. During the evaluation phase, problems that occur during data learning are identified and resolved and research objectives must also be achieved. The evaluation that will be used in this study refers to the Kirkpatrick evaluation model [28]

Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The following equation represents the content-validity coefficient (V):

$$\mathbf{V} = \frac{\sum \mathbf{s}}{[\mathbf{n}(\mathbf{c}-\mathbf{1})]} \qquad \mathbf{(1)}$$

Remarks:
Io = the lowest validity score (in this case = 1)
c = the highest validity score (in this case = 5)
r = expert judgment score
s = r – Io
c = number of experts
V = content-validity coefficient (between 0-1)[29]

To determine the effect of metacognition integration in online science learning on students' HOTS, analysis of General Linear Model and Multivariate Analysis of Variance. MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the Effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [30]–[32].

3. RESULT AND DISCUSSION

3.1. Result

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education programs at seven public universities and fourteen private universities in Indonesia revealed that the students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of the material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement.

The design of the metacognition-integrated science learning model produced in the *Design* stage is shown in Figure 2. The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' higher-order thinking skills (HOTS). The lesson plan comprises 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, Learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project.

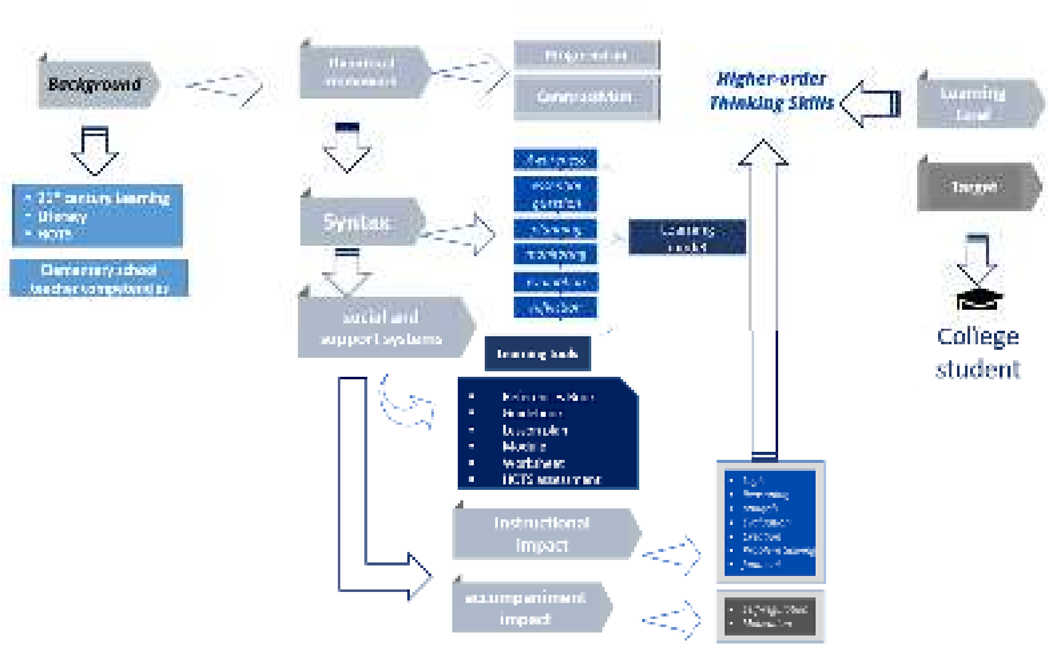

Figure 2. Online science learning model integrated metacognition

The *Develop* Stage generated the data on the model's content and construct validity test results.

Table 1. Expert Judgement on the Model's Content Validity

Product	Aspect	V-Score	Criteria
The Model's Book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language Use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language Use	0.911	Valid (high)
Lesson plan		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the PhET simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to [33] criteria for practicality, the learning model was implemented successfully for the students that participated in this study.

To investigate the extent of the treatment impact, hypotheses were tested using the General Linear Model (GLM) and Multivariate of Variance (MANOVA). Four assumptions must be met for this test to be valid: 1) an independent observer, 2) a random sample, and 3) normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (< 0.05). In an experimental study, the error factor (subject, sample, treatment, etc.) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [34]. The uniformity of data in an experiment can be overlooked [35]. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [36].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by Tests of Within-Subjects Effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the Mean Different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14.923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS (Table 2).

Table 2. Multivariate Tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
experiment	Pillai's trace	.745	45.419[a]	7.000	109.000	.000	.745
	Wilks' lambda	.255	45.419[a]	7.000	109.000	.000	.745
	Hotelling's trace	2.917	45.419[a]	7.000	109.000	.000	.745
	Roy's largest root	2.917	45.419[a]	7.000	109.000	.000	.745
Control 1	Pillai's trace	.354	8.530[a]	7.000	109.000	.000	.354
	Wilks' lambda	.646	8.530[a]	7.000	109.000	.000	.354
	Hotelling's trace	.548	8.530[a]	7.000	109.000	.000	.354
	Roy's largest root	.548	8.530[a]	7.000	109.000	.000	.354
Control 2	Pillai's trace	.684	33.638[a]	7.000	109.000	.000	.684
	Wilks' lambda	.316	33.638[a]	7.000	109.000	.000	.684
	Hotelling's trace	2.160	33.638[a]	7.000	109.000	.000	.684
	Roy's largest root	2.160	33.638[a]	7.000	109.000	.000	.684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column [37]. A partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. The value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5) [30]–[32]. The effect size of the metacognition integrated learning model on students' HOTS was quite large because it was more than 50%. The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

3.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' higher-order thinking skills (HOTS) to solve problems and make sound decisions in their life after graduation. Higher-order thinking skills (HOTS) are inextricably linked to technological, pedagogical, and content knowledge (TPACK) [38], [39]. These abilities are critical for developing students' problem-solving abilities [40]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [41], which is especially critical in elementary school science instruction.

Syntax of the learning model established in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: 1) awareness of knowledge/person factors, 2) awareness of thought/task variables, and 3) awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [42]. These three elements are represented in the learning model's *awareness* step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [43].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [21]–[23]. Planning, monitoring, and assessing are all components of metacognition [44]. The three are then included in the learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, PhET, and sound meter software, as well as video presentation projects, are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness) concerning the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' higher-order thinking skills (HOTS) in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occurring around them [45]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mind-mapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [46], [47]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems [48].

The advantages of the metacognition-integrated learning model are as follows: (1) the model was developed using scientific procedures that are quantifiable and involve experts; (2) the model can be implemented in normal or pandemic conditions by adjusting the learning activities; 3) the learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; 4) the learning model was designed based on real-world situations; 5) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

4. CONCLUSION

This research contributes to the development of science in the form of an innovative science learning model integrated with metacognition strategies. Metacognition can be integrated into online science learning through awareness, essential questions, planning, monitoring, evaluating, and reflecting. The lesson plans and teaching materials were developed regarding this syntax via instructional activities that strengthen metacognitive skills. The expert's judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' higher-order thinking skills (HOTS), as seen by a 75% (large effect) increase in response to the model's implementation. Changes in student behavior and character that appeared during the application of the model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation. The limitation of this study is that the effect of this model has only been measured on the HOTS variable in total, further analysis has not been carried out on the HOTS aspects separately (logic, reasoning, analysis, evaluation, creation, problem-solving, and judgment). Changes in behavior and character that appear during the application of this learning model are very diverse, but researchers only limit them to HOTS. Other characters have not been observed.

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Promoting higher-order thinking skills during online learning: The integration of metacognition in science for higher education

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ABSTRACT

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' high order thinking skills (HOTS). The analyze, design, develop, implement, and evaluate (ADDIE) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a general linear model and multivariate analysis of variance. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

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1. INTRODUCTION

Science is critical for pre-service elementary teachers. Based on the results of a preliminary study on 21 primary school teacher education programs in Indonesia, science education is offered through courses that emphasize science content and science learning development. These courses are geared toward increasing technological pedagogical and content knowledge (TPACK). If the students' science content is good, it will have a positive impact on their TPACK. Therefore, content knowledge can support the realization of TPACK [1], [2]. Graduates of the primary school teacher education department should be able to master science concepts and design learning that takes pedagogic, content, and technological factors into account. Besides TPACK, the students from the primary school teacher education (PSTE) department should also develop higher-order thinking skills (HOTS) to deal with the complexity of science. Unfortunately, Indonesian students have many misconceptions about scientific principles [3], face difficulty learning science [4], and have poor performance in science.

In addition, the occurrence of the COVID-19 pandemic requires the delivery of science instruction online, which posed a significant threat to professors, who had to experiment with educational technologies. Faculty members and students at universities must swiftly adjust to online learning, particularly to experimental and live demonstration-based learning. Students must be technologically savvy to accomplish science education online. To achieve success in online learning, students need to increase their motivation, autonomy, problem-solving skills, collaboration skills, decision-making skills, and thinking skills, which are also known as 21st-century skills.

The 21st century skills have become a topic of discussion among several educational institutions, practitioners, and experts. The 21st century requires the following skills: critical thinking, problem-solving skills, communication skills, and collaboration skills [5]. In addition, assessment and teaching of 21st century skills (ATC21S) classifies 21st-century skills into four areas; one of which is methods of thinking [6]. A cognitive or thinking process involves multiple phases of thought, including remembering, understanding, applying, analyzing, and making decisions. This mode of reasoning is known as HOTS.

The lecturers continue to struggle with teaching HOTS and preparing their students to use higher-order thinking in everyday life. Learning that continues to emphasize the development of lower-level thinking skills (LOTS) contributes to the poor HOTS of teachers in Indonesia [7]. This could be due to the instructors' lack of expertise regarding how to hone students' higher-order thinking skills [8]. According to studies [9], [10], the LOTS group contains a greater number of future primary school teachers students than the HOTS category. Therefore, a learning model in higher education is needed that empowers HOTS by involving students mentally and cognitively in every learning process.

Countless studies indicate that the educational approach used in Education Personnel Education Institutions has been ineffective in promoting HOTS in students. In Indonesia, research continues to be centered on students' HOTS analysis and the creation of HOTS-based assessments. The learning models implemented to develop HOTS in students, such as problem-based learning (PBL) [11], reading, mapping, and sharing (RMS) [12], conceptual understanding procedures (CUPs) [13], constructive conflict (CC), and modified free inquiry (MFI) [14], film [15], and guided inquiry laboratory-based module (GILM) [16] mostly focused on the cognitive processes and disregard differences in learning between individuals. Therefore, a more-in depth analysis is needed to address the use of learning methods to maximize student autonomy. As a result, integrating metacognition into the learning process is the optimal strategy for improving college students' HOTS.

Metacognition is chosen as an alternative problem-solving strategy which consists of two important stages, namely metacognition knowledge and metacognition regulation. The results of the previous studies show the advantages of metacognition as a learning strategy, namely that it can: i) help students monitor their progress and control their learning process (through reading, writing, solving problems); ii) contribute to students' learning desire their intellectual abilities [17], [18]; iii) improve academic achievement across age, cognitive abilities, and learning domains [19], [20]; and iv) help students transfer what they learn from one context to the next, or from a previous task to a new task. Metacognition optimization is expected to be able to maximize students' thinking skills in overcoming real-world problems.

Students can engage in metacognitive activities, such as: i) Reflecting on the thought processes involved in the learning process; ii) Seeking concrete examples from prior learning experiences and mindsets; iii) Analyzing the benefits of using the mindset versus the disadvantages of not using it, resulting in an understanding of when the strategy should be used; iv) Making generalizations and formulating rules about these thought patterns; and v) Naming the thought pattern [21]–[23]. This integration is consistent with students' qualities as adult learners who are frequently required to make decisions while studying autonomously. Hence, the research questions for this study were: i) What role does metacognition play in an online learning model?; ii) To what extent is metacognition-integrated online learning effective in promoting students' HOTS in science?

2. RESEARCH METHOD

The current research and development (R&D) study used the Analysis, Design, Develop, Implement, dan Evaluate (ADDIE) model [24] to develop a feasible and effective metacognition-based science education for college students. The research design is presented in Figure 1.

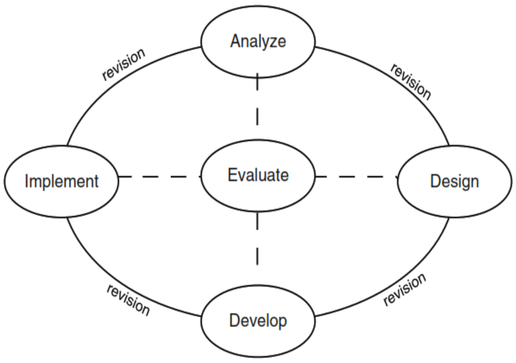

Figure 1. The ADDIE procedure

The urgency of developing the learning model as well as problem analysis was carried out at the analyze stage. A needs analysis was conducted through depth interviews. The depth interview has been carried out by involving 21 science lecturers in the elementary school teacher education department seven state universities and 14 private universities in Indonesia. The results of the need assessment show that: i) The variability of the educational background of primary school teacher education's students causes the interest and speed in understanding science material to vary; ii) The selection of learning models becomes difficult because of this diversity factor; iii) Students' creativity is still lacking so that their ability to develop ideas is not optimal; iv) Mastery practice and presentation skills are still lacking; v) Reading interest is lacking so that their ability to understand concepts is still low and even has the potential for misconceptions; and vi) Students' understanding is still at cognitive level 1 (memorization) so it needs to be encouraged to reach a higher level.

At the Design stage, the product's design and draft were created. At the Develop stage, the validation process, product revision, expert validation, and field try-outs were conducted to ensure that the final product was valid in both contents (expert judgment) and construct (experimental study). Content validity is carried out to determine the feasibility of the learning model based on expert judgment [25]. Construct validity was carried out to determine the effectiveness of the learning model towards increasing HOTS [26], [27]. The process of implementing the learning model on a wider scale is carried out at the Implement stage. Content validation with the Delphi technique involved seven experts. The experts came from educational technology experts, science education experts, physicists, learning evaluation experts, educational science experts, and two science lecturers from the elementary school teacher education study program. While the construct validity was conducted to test the effectiveness of the model through an experimental study by randomized pretest-posttest comparison group design. The construct validity examination was conducted at two universities using randomly selected classes from Universitas Ahmad Dahlan and Universitas Sarjanawiyata Tamansiswa, Indonesia. The effectiveness test involved three homogeneous groups to determine the robustness of the metacognitive integrative model. The experimental group was compared with two control groups who were given the model treatment commonly used by lecturers, namely problem-based learning (control 1) and experiment (control 2). The study involved 41 students as the experimental group, 39 students as the control group 1, and 39 students as the control group 2.

Evaluation is carried out at the process stage and the end of the activity, namely from the analysis, design, development, and implementation stages. The evaluation stage in this study uses formative and summative because it is related to the application of new learning models. The goal is to determine whether the objectives of the model are met and determine what is needed to increase the effectiveness of the model. After the implementation of the model is complete, a summative evaluation is carried out to determine the impact of implementing the model on learning. During the evaluation phase, problems that occur during data learning are identified and resolved and research objectives must also be achieved. The evaluation that will be used in this study refers to the Kirkpatrick evaluation model [28]

Aiken's V (content-validity coefficient (V)) formula was used to examine the content validity test findings. This analysis was done by assigning a number between 1 (highly unrepresentative/irrelevant) to 5 (highly representative/relevant) to the product's contents being evaluated. The (1) represents the content-validity coefficient (V):

$$V = \frac{\sum s}{[n(c-1)]} \quad (1)$$

Remarks:
Io = the lowest validity score (in this case=1)
c = the highest validity score (in this case=5)
r = expert judgment score
s = r – Io
c = number of experts
V = content-validity coefficient (between 0-1) [29]

To determine the effect of metacognition integration in online science learning on students' HOTS, analysis of general linear model and multivariate analysis of variance. MANOVA was used to see the effect of online science learning on college students' HOTS. The significance of the effect was then measured by calculating the effect size. The effect size metric indicated the standardized difference in scores between the control and experimental groups. In this study, the effect Size used was Cohen's d, where the effect size shows the magnitude of the difference in scores between the control and experimental groups. MANOVA calculates effect size using Eta squared, with a standard Eta score of 0.01 for a small effect, 0.3 for a medium effect, and 0.5 for a large effect [30]–[32].

3. RESULTS AND DISCUSSION

3.1. Results

The analysis of open-ended questionnaires distributed to 21 science lecturers in primary school teacher education programs at seven public universities and fourteen private universities in Indonesia revealed that the students' varied educational backgrounds resulted in differences in their interest and ability to comprehend science material. This variability complicates the process of selecting learning models. Additionally, these pupils exhibit a lack of creativity, which impairs their capacity to generate ideas. Students' mastery of practice and presenting skills is still weak, with their comprehension of the material being at the cognitive level 1 (memorization). Due to the students' lack of interest in reading, their capacity to comprehend topics remains limited and may even result in misconceptions. The urgency of generating a metacognition-integrated science learning model to improve students' HOTS may be seen in the HOTS of students who are still developing and in need of improvement.

The design of the metacognition-integrated science learning model produced in the Design stage is shown in Figure 2. The metacognition integrated learning model is made up of the following components: objectives, time allocation, syntax, social system, support system, reaction principle, instructional and accompaniment impact, and learning outcomes. Metacognitive stages were incorporated into the development of lesson plans, modules, worksheets, media, and instruments for assessing students' HOTS. The lesson plan comprises 14 synchronous and asynchronous online meetings. The module includes a title page, a foreword, a table of contents, instructions for using the module, learning activities 1–7, summative tests, answer keys, feedback and follow-up, and the author's biography and bibliography. Each learning activity consists of learning indicators, awareness, mind mapping activity, materials, independent projects, summaries, reflections, and formative tests. Attachments to the project include worksheets, media presentations, and learning assessments that feature problems and explanations regarding the project. The Student Worksheet incorporates metacognitive stages and includes a brief description of the learning activity, a material map, an activity guide, a study guide, learning objectives, and a video production project. The Develop Stage generated the data on the model's content and construct validity test results.

The implementation of the learning model was evaluated by observing the sample class's synchronous and asynchronous learning processes. Observations were made via Google Classroom monitoring to efficiently monitor the learning syntax. Each stage of the learning process was conducted online using Google Classroom, Google Meet, Google Forms, YouTube, and the physics education technology (PhET) simulation. The results of these observations showed a score of 92.1 for the implementation of the learning model. According to Koyan [33], criteria for practicality, the learning model was implemented successfully for the students that participated in this study. Expert judgement on the model's content validity is shown in Table 1.

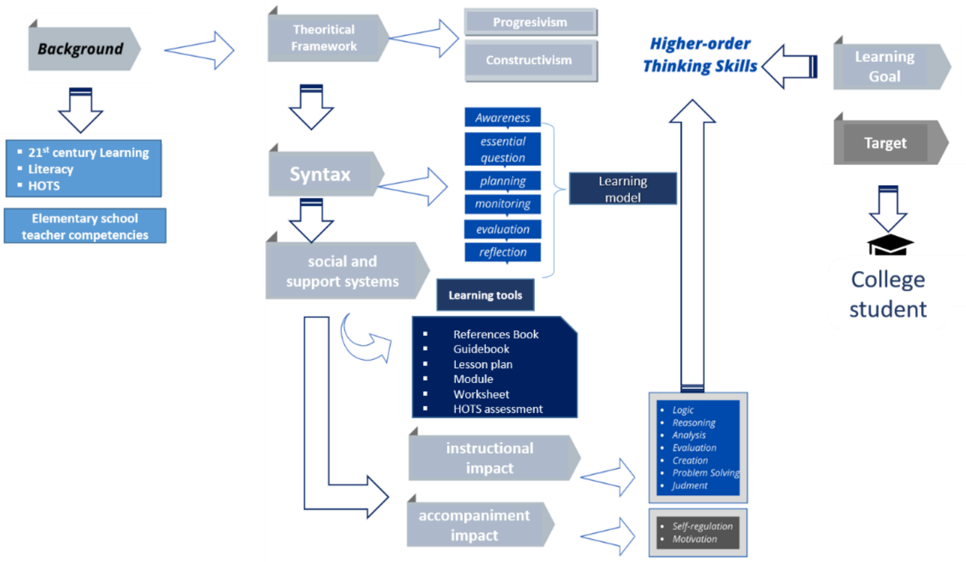

Figure 2. Online science learning model integrated metacognition

Table 1. Expert judgement on the model's content validity

Product	Aspect	V-Score	Criteria
The model's book	Content	0.931	Valid (high)
	Presentation	0.918	Valid (high)
	Language use	0.934	Valid (high)
Guidebook	Content	0.926	Valid (high)
	Presentation	0.904	Valid (high)
	Language use	0.911	Valid (high)
Lesson plan		0.877	Valid (high)
Module		0.853	Valid (high)
Worksheet		0.907	Valid (high)
HOTS assessment tool		0.879	Valid (high)

To investigate the extent of the treatment impact, hypotheses were tested using the general linear model (GLM) and multivariate of variance (MANOVA). Four assumptions must be met for this test to be valid: an independent observer, a random sample, also normal and homogenous data. Methodologically, assumptions 1 and 2 were met, but evaluating assumption 3 resulted in normal data in each experimental and control group, but not homogeneous data, as the sig. value in Box's M was 0.000 (<0.05). In an experimental study, the error factor (subject, sample and treatment) has a large influence on the changes in the subject's score from pre- to post-test. There is no way that all subjects in the experimental group will have the identical gain in test scores. This inhomogeneity can be overlooked because obtaining the same variation un scores across the three groups subjected to different treatments is challenging [34]. The uniformity of data in an experiment can be overlooked [35]. ANOVA is a robust test for data heterogeneity disturbances, provided that the number of samples in each group is between 7 and 15 participants [36].

The results of hypothesis testing using GLM-MANOVA can be seen in the Appendix. The analysis of Mauchly's Test of Sphericity showed that the results were significant. Thus, it was followed by tests of within-subjects' effects to see the interaction between variables. There was an interaction between time (pre-post-test) and group (experiment-control). The interaction showed that the change in pretest to posttest scores in the three groups (experiment-control 1-control 2) was significantly different. The next step was to analyze the mean different (MD) on Pairwise Comparison which indicated that the MD for the experimental group was -17.505 with a sig. value of 0.000 (<0.05). This means that there was a significant increase in HOTS in the experimental group. In control group 1, the MD value was -11.069* while the sig value was 0.001, indicating a significant increase. Similarly, reported by control group 2, the MD value was -14.923 and the sig value was 0.000, which means that there was a significant increase in the participants' HOTS. However, based on the three MD values, the experimental class experienced the greatest gain, with a difference of 17.505 between the pretest and posttest mean scores. Additionally, the results of the multivariate test were interpreted to establish the model's efficacy in improving students' HOTS as shown in Table 2.

Table 2. Multivariate tests

Learning model		Value	F	Hypothesis df	Error df	Sig.	Partial eta squared
experiment	Pillai's trace	.745	45.419[a]	7.000	109.000	.000	.745
	Wilks' lambda	.255	45.419[a]	7.000	109.000	.000	.745
	Hotelling's trace	2.917	45.419[a]	7.000	109.000	.000	.745
	Roy's largest root	2.917	45.419[a]	7.000	109.000	.000	.745
Control 1	Pillai's trace	.354	8.530[a]	7.000	109.000	.000	.354
	Wilks' lambda	.646	8.530[a]	7.000	109.000	.000	.354
	Hotelling's trace	.548	8.530[a]	7.000	109.000	.000	.354
	Roy's largest root	.548	8.530[a]	7.000	109.000	.000	.354
Control 2	Pillai's trace	.684	33.638[a]	7.000	109.000	.000	.684
	Wilks' lambda	.316	33.638[a]	7.000	109.000	.000	.684
	Hotelling's trace	2.160	33.638[a]	7.000	109.000	.000	.684
	Roy's largest root	2.160	33.638[a]	7.000	109.000	.000	.684

Each F tests the multivariate simple effects of time within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.
a. Exact statistic

The metacognition integrated science online learning model has been found to influence students' HOTS based on the sig. values in Table 1. The effective contribution of the treatment can be seen in the Wilks' Lambda column [37]. A partial Eta Squared of 0.745 suggests that the treatment can increase HOTS by 74.5% in the experimental group, 35.4% in the control group 1, and 68.4% in the control group 2. The value of partial eta square indicates the magnitude of the effect size of an action (small effect of 0.01; medium effect of 0.3; while the large effect of 0.5) [30]–[32]. The effect size of the metacognition integrated learning model on students' HOTS was quite large (more than 50%). The metacognition integrated science online learning approach has a considerable effect on students' HOTS, with an effect size of 74.5%.

3.2. Discussion

This study successfully developed a practical and valid metacognition-integrated science online learning model, effective in improving college students' HOTS to solve problems and make sound decisions in their life after graduation. HOTS are inextricably linked to knowledge TPACK [38], [39]. These abilities are critical for developing students' problem-solving abilities [40]. With strong HOTS, students may observe and investigate environmental issues objectively, reflect on their experiences to propose alternative solutions, and are capable of precisely and quickly solving issues while making decisions. Students with a high HOTS score can strengthen their capacity to integrate pedagogical knowledge, content, and technology into their learning [41], which is especially critical in elementary school science instruction.

Syntax of the learning model in this study is the product of metacognition theory integration. Metacognition is comprised of knowledge and regulation components. Metacognitive knowledge is composed of three components: i) Awareness of knowledge/person factors; ii) Awareness of thought/task variables; iii) Awareness of thought/strategy variables. Declarative, procedural, and conditional knowledge are all examples of metacognitive knowledge [42]. These three elements are represented in the learning model's Awareness step. Metacognitive regulation is the subjective internal response of an individual to metacognitive knowledge. This response is aimed at developing a strategy to resolve an issue. Metacognitive control is the process of observing cognitive activity and ascertaining if cognitive objectives are met [43].

Metacognition activities can be carried out through five activities. The first activity is to reflect on the cognitive processes that occur during the learning process. The second exercise is to seek out additional tangible instances of previous learning experiences and mental patterns. The third action is to weigh the benefits and drawbacks of adopting the mindset. The fourth task is to draw generalizations and establish rules about this pattern of reasoning. The last activity is to name the pattern of thinking in the form of a learning strategy [21]–[23]. Planning, monitoring, and assessing are all components of metacognition [44]. The three are then included in the learning model's stages, namely planning, monitoring, and reflection.

The metacognition integrated learning model prioritizes students' independence and freedom of thought in solving problems through work-making projects. Students in this study were asked to identify contextual learning challenges related to motion and force, work and energy, electricity, magnetism, wave and sound vibrations, light and optical instruments, as well as the earth and solar system. Mind mapping, contextual projects in the surrounding area, virtual projects employing Tracker, PhET, and sound meter software, as well as video presentation projects, are all examples of problem-solving exercises done by the students. Each lesson began with activities that help the students identify their strengths and limitations (awareness) concerning the notion of science, followed by activities that help them develop problem-solving strategies (planning, monitoring, evaluating).

The increase in the research participants' HOTS in terms of logic, reasoning, and analysis during the implementation of the learning model can be seen from the students' ability to analyze science problems occurring around them [45]. These students were tasked with the responsibility of resolving problems through project-based activities. Each lesson required students to complete various projects, including mind-mapping, scientific experiments (contextual and virtual), and video presentations. The mind mapping projects encouraged students to read and understand the content using logic and reasoning. They were also asked to assess problems throughout the process of completing science projects such as building simple automobiles, electrical circuits, simple compasses, simple pendulums, and solar system simulations. Additionally, these students were accustomed to discussing problems with their peers to resolve them and hone their problem-solving abilities.

When the participants evaluated their achievement of the learning objectives, the appropriateness of the work generated with the challenge, and the suitability of time and approach with the expected results, their HOTS in the evaluation component grew significantly. The increase in creation happened as a result of pupils becoming accustomed to creating projects that serve as the output of assignments. At this stage, opinions were gathered, clarified, logically reasoned, and expressed to others [46], [47]. During the implementation of the model, aspects of problem-solving and judgment were also emphasized at each step of learning. For instance, many students struggled when analyzing the motion of objects (wind-powered automobiles) using Tracker software. Despite the availability of tutorials, some students were still unable to complete their work by the deadline. This occurred because some of these students technically mishandled the program used for analysis. The lecturer asked students who had successfully finished the project to mentor other students at a virtual face-to-face meeting. This accomplishment occurred as a result of students' willingness to experiment with various methods for solving issues, such as using MS Excel for mathematical operations and graph creation. Students who develop strong problem-solving and judgment skills will develop into self-assured, creative, and self-sufficient thinkers. The society produced by these individuals is capable of easily resolving life problems [48].

The advantages of the metacognition-integrated learning model are: i) The model was developed using scientific procedures that are quantifiable and involve experts; ii) The model can be implemented in normal or pandemic conditions by adjusting the learning activities; iii) The learning model's syntax contains activities that teach students to make decisions, be accountable for decisions, and complete complex tasks responsibly; iv) The learning model was designed based on real-world situations; v) The inclusion of projects in the learning model enables the creation of open-ended solutions, thereby preparing students to be effective problem solvers.

4. CONCLUSION

This research contributes to the development of science in the form of an innovative science learning model integrated with metacognition strategies. Metacognition can be integrated into online science learning through awareness, essential questions, planning, monitoring, evaluating, and reflecting. The lesson plans and teaching materials were developed regarding this syntax via instructional activities that strengthen metacognitive skills. The expert's judgment was used to determine the model's feasibility, which resulted in a high level of practicality. The experimental study showed that the learning model had a considerable influence on students' HOTS, seen by 75% (large effect) increase in response to the model's implementation. Changes in student behavior and character that appeared during the application of the model were very diverse, but we only limited them to HOTS. Other unobserved characteristics, such as discipline, responsibility, and independence, are suggested for further investigation in the model's subsequent implementation.

The limitation of this study is that the effect of this model has only been measured on the HOTS variable in total, further analysis has not been carried out on the HOTS aspects separately (logic, reasoning, analysis, evaluation, creation, problem-solving, and judgment). Changes in behavior and character that appear during the application of this learning model are very diverse, but researchers only limit them to HOTS. As a recommendation, further research is needed to observe other characters that appear during the implementation of this model. Each individual has a different style of learning which has an impact on different metacognition. Lecturers need to facilitate these individual differences so that each student feels treated fairly in learning.

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Promoting higher-order thinking skills during online learning: The integration of metacognition in science for higher education

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Abstract

This study aimed to explore the integration of metacognition in online science education for college students and tested the feasibility of the learning model on students' high order thinking skills (HOTS). The analyze, design, develop, implement, and evaluate (ADDIE) model was employed in this study. A needs analysis was conducted through interviews and questionnaire surveys to 21 science lecturers from primary school teacher education study programs at seven state universities and 14 private universities in Indonesia. In the development phase, the effectiveness of the model was examined through an experimental study involving three groups of students: experimental group (41 students), control group 1 (39 students), and control group 2 (39 students). The experimental study was performed using the randomized pretest-posttest comparison group design. The research hypothesis was investigated using a general linear model and multivariate analysis of variance. Through awareness-building, essential questioning, planning, monitoring, evaluating, and reflecting, this study successfully integrated metacognition into online science education. The model's learning syntax incorporated both synchronous and asynchronous learning activities. Virtual and contextual projects are critical components of this approach because they demonstrate how metacognition is regulated. Expert judgment indicated that the model under development was highly feasible. The experimental study established that the learning model had a considerable effect on students' HOTS, which rose by 75% (a large effect) due to the model's implementation.

Keywords

HOTS; Metacognition; Online learning; Science education

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