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The Effect of Science e-Module to Enhance Students' Critical Thinking Skills on the Object Classification Topic

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Abstract: This study aims to develop innovative science teaching materials based on higher-order thinking skills (HOTS) to enhance students' critical thinking skills on the topic of object classification. The research adopted the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The study involved 60 seventh-grade junior high school students as research subjects. Data were collected using expert validation sheets, student response questionnaires, and pretest-posttest instruments to assess students' critical thinking skills. The results of expert validation indicated that the developed teaching materials were categorized as "highly valid," with an average score of 92.5%, reflecting the quality in terms of content, presentation, language, and design. During implementation, students showed an increase in critical thinking performance. The average pretest score was 58.3, which improved to 78.7 in the posttest. A paired sample t-test analysis revealed a statistically significant difference between pretest and posttest scores ($t = 8.624$; $p < 0.001$), indicating the effectiveness of the developed material in improving critical thinking skills. Furthermore, student responses to the teaching materials were very positive, with an average score of 88.4%, suggesting that the materials were well-received and engaging. This study provides empirical support for integrating innovative HOTS-oriented learning materials into science instruction, particularly for foundational topics such as object classification. The findings contribute to the field of science education research and offer practical implications for the development of curriculum materials that foster critical thinking in junior high school students. These results can be used as a reference for educators and curriculum developers in designing effective, student-centered science learning tools.

Keywords: ADDIE model, critical thinking, instructional design, object classification, science teaching materials.

▪ INTRODUCTION

Critical thinking is a foundational competency in 21st-century education, emphasizing students' ability to analyze information, evaluate arguments, and make reasoned decisions based on evidence (Cottrell, 2005; Brickman et al., 2009; Walsh et al., 2019). Operationally, critical thinking involves skills such as interpretation, analysis, inference, explanation, and evaluation skills essential for scientific literacy and problem-solving. This study adopts the framework of Facione (1990), which defines critical thinking as comprising six core cognitive skills: interpretation, analysis, evaluation, inference, explanation, and self-regulation. These indicators serve as the basis for both the development of teaching materials and the construction of the assessment rubric used to measure student outcomes. Despite its importance, studies consistently report that Indonesian students demonstrate relatively low levels of critical thinking. This is supported by the results of the Programme for International Student Assessment (PISA), which in 2018 showed that Indonesian students scored 396 in reading, 379 in

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mathematics, and 396 in science, significantly below the OECD average, indicating weaknesses in higher-order thinking and problem-solving skills (OECD, 2019). Mainly due to the dominance of traditional teaching methods and the lack of instructional materials explicitly designed to foster higher-order thinking (Solihati & Hikmat, 2018; Nurhasanah et al., 2024).

One topic in junior high school science with strong potential to cultivate critical thinking is object classification. This topic requires learners to observe, compare, and group objects based on their characteristics, and to analyze their relevance and function in daily life (Rahmawati et al., 2021). The classification process engages students in identifying distinguishing features, recognizing patterns, and making decisions; these activities reflect core components of critical thinking, as proposed by Facione (1990), including analysis, inference, and evaluation. For instance, when classifying living organisms, students must differentiate relevant characteristics (analysis), draw conclusions about similarities and differences (inference), and justify their classifications (evaluation). However, in many classrooms, this topic is still delivered procedurally, with limited student engagement in analytical or evaluative tasks (Anggraenya & Khongput, 2022).

To address these limitations, various pedagogical strategies have emerged. Problem-based learning (PBL) and discovery learning are well-established approaches that have improved critical thinking in science education (Bilgin, 2009). Similarly, digital and contextual instructional media, including Android applications, augmented reality, and locally based learning resources, have enhanced student engagement and science literacy (Fahmi et al., 2022). These innovations underscore the growing emphasis on designing materials that are both interactive and aligned with students' real-world experiences.

However, a specific gap remains unaddressed: no prior research has focused on developing science teaching materials that explicitly target critical thinking through the topic of object classification and its real-world implications. While several previous studies have introduced technology-based approaches (Pahrudin et al., 2021) or applied inquiry-driven learning models (Pursitasari et al, 2020), these works primarily emphasize general scientific reasoning or abstract problem-solving skills. Khaeruddin et al. (2023), for instance, developed HOTS-oriented science modules on environmental sustainability, but did not explore the classification process as a cognitively rich context for fostering analytical and evaluative thinking. In contrast, classification tasks inherently involve comparing characteristics, making inferences, and justifying groupings processes that align directly with critical thinking indicators such as analysis and evaluation (Facione, 1990).

Thus, the novelty of this study lies in its integration of object classification with explicit critical thinking outcomes in a contextually relevant and pedagogically sound framework. By situating classification not merely as a procedural skill but as an opportunity for students to engage in higher-order thinking, this study addresses a specific pedagogical gap in the development of HOTS-based science teaching materials.

This study aims to develop innovative science teaching materials on the topic of object classification, explicitly designed to enhance junior high school students' critical thinking. The development follows the ADDIE model, which comprises Analysis, Design, Development, Implementation, and Evaluation, allowing for systematic alignment with learners' needs and curricular goals (Sinaga et al., 2017; Spatioti et al., 2022). The expected outcome is a set of valid, engaging, user-friendly materials that demonstrably foster students' ability to think critically and reflectively.

In doing so, this research contributes to the limited but growing body of work on HOTS-oriented science instruction in Indonesia. It responds to both national curriculum directives and international benchmarks (UNESCO, 2002) that underscore the importance of equipping students with 21st-century competencies. Furthermore, this study provides a practical reference for educators and curriculum developers seeking to implement high-quality, context-based science education that meets contemporary academic and societal needs (Wibowo, 2015).

▪ METHOD

Participant

The subjects of this study were 60 seventh-grade students from a public junior high school in Banjarmasin, Indonesia. Participants were selected using purposive sampling. The school was chosen based on specific criteria such as the availability of basic digital infrastructure, the readiness of teachers to collaborate, and the school's willingness to integrate newly developed teaching materials.

The participants were divided into two groups based on existing class groupings to maintain the natural classroom environment and minimize disruption. Specifically, one intact class of 30 students was assigned as the experimental group, receiving instruction using the developed teaching materials on object classification. In contrast, another intact class of 30 students served as the control group, receiving conventional science instruction using standard teaching materials. Random assignment was not conducted due to logistical and ethical considerations within the school setting.

The demographic composition of the participants included both male and female students, with ages ranging from 12 to 13 years old. To ensure the baseline equivalence of the two groups, a pre-test on critical thinking skills was administered prior to the intervention, and the results were statistically compared to confirm that there was no significant difference in students' initial abilities.

Furthermore, this study adhered to ethical research standards. Informed consent was obtained from the school administration and students' guardians before the research was conducted. Participation was voluntary, and students were informed that they could withdraw at any point without academic consequences.

Research Design and Procedures

This research and development (R&D) study employed the ADDIE model, which consists of Analysis, Design, Development, Implementation, and Evaluation, chosen for its structured yet flexible nature that supports systematic material development and iterative refinement (Branch, 2009). Each phase was executed collaboratively with stakeholders to develop science teaching materials on object classification aimed at enhancing students' critical thinking.

In the Analysis phase, needs were identified through curriculum review, teacher interviews, and analysis of existing materials. The Design phase involved creating a blueprint for student modules and interactive digital media, including learning goals, assessments, and instructional flow.

During Development, the materials were drafted and validated by three experts: two science education lecturers and one media designer, using a rubric that assessed content accuracy, language clarity, instructional design, visual quality, and alignment with Facione's (1990) critical thinking indicators. Feedback was integrated through iterative revisions following expert review and pilot implementation.

The Implementation phase involved a six-week classroom trial (12 teaching sessions, two assessments) with 30 seventh-grade students taught by a trained teacher. Student engagement was monitored by two observers using structured observation sheets focused on critical thinking behaviors.

In the Evaluation phase, formative evaluation was conducted through expert validation, and summative evaluation was conducted through a pretest–posttest consisting of 10 multiple-choice and 5 open-ended questions that targeted critical thinking aspects, including interpretation, analysis, inference, and evaluation (Facione, 1990). The instruments were reviewed by experts for content validity and pilot-tested to ensure reliability. Observation data supported the quantitative findings.

This iterative ADDIE cycle ensured the final product was pedagogically sound and contextually relevant (Molenda, 2003; Wijayanti et al., 2020), aligning with previous findings on the model's effectiveness in developing high-quality instructional tools (Nieveen & Folmer, 2013; Rukoyah & Bektiningsih, 2024).

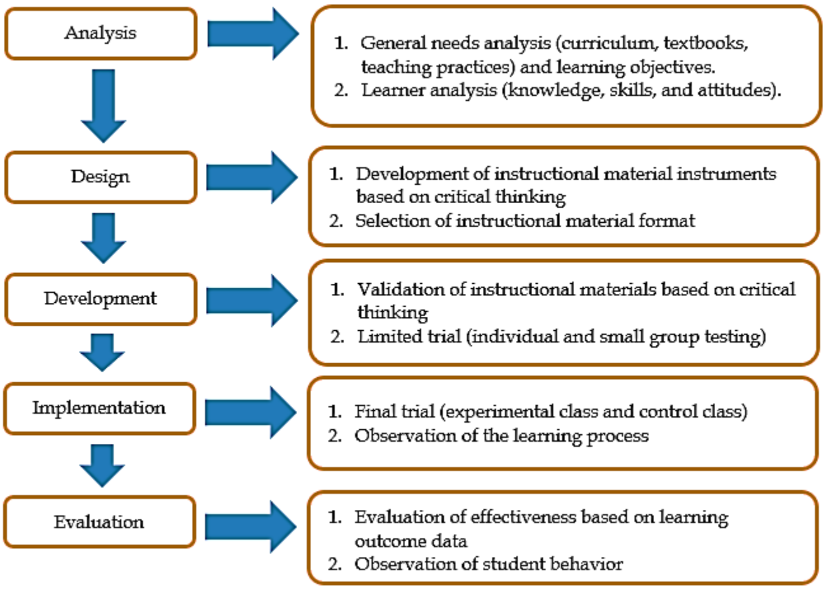


Figure 1. Research implementation flow using the ADDIE model

Instruments

The effectiveness was evaluated using a pretest-posttest consisting of 10 multiple-choice and five open-ended questions developed to assess critical thinking indicators based on Facione's (1990) framework, including interpretation, analysis, inference, and evaluation. The items and scoring guidelines were validated through expert review for content validity and pilot testing to ensure reliability. Additionally, two observers monitored student engagement using structured observation sheets focused on critical thinking behaviors.

Data Analysis

The research was conducted after the initial prototype of the teaching materials was developed. These materials were then validated by three expert reviewers, including two academic experts in science education and one instructional media practitioner. A Likert scale-based questionnaire (scale 1-4) was used to assess six key aspects: format, language, content accuracy, presentation quality, usefulness, and integration of critical thinking elements.

The validation process employed a quantitative rubric, in which the scoring weights were as follows: a score of 4 indicated "very valid," 3 meant "valid," 2 represented "less valid," and one indicated "not valid" (Arikunto, 2013). The validity of the instructional material was determined based on its alignment with theoretical foundations, as assessed by the validators. If a component was deemed invalid, it was revised accordingly. The same six aspects format, language, content, presentation, usefulness, and integration of critical thinking served as the evaluation criteria.

The scores were interpreted using specific rating categories, where a score between 3.26 and 4.00 indicated that the material was "very valid," scores between 2.51 and 3.25 were considered "valid," scores from 1.76 to 2.50 were categorized as "invalid," and those between 1.01 and 1.75 as "very invalid" (Arikunto, 2013).

Based on this percentage, the following criteria were applied: instructional materials scoring between 85.01% and 100.00% were considered "valid without revision," scores from 70.01% to 85.00% required "minor revision," scores between 50.01% and 70.00% indicated the need for "major revision," and scores below 50.01% were categorized as "not valid" (Arikunto, 2013).

After validation and necessary revisions, the materials were implemented in real classroom settings over six weeks, consisting of 14 sessions, 12 instructional sessions, and two assessment sessions. To evaluate the effectiveness of the materials, students' critical thinking skills were measured using a pretest and posttest instrument. The instrument, adapted from Ennis (2011), included key indicators such as interpretation, analysis, inference, and evaluation. It was validated by two science education experts and tested for reliability using Cronbach's Alpha, which yielded a value of $\alpha = 0.82$, indicating high internal consistency.

Effectiveness was analyzed using the normalized gain (n-gain) formula. Based on Hake (1998), an n-gain value greater than 0.7 was categorized as "high," between 0.3 and 0.7 as "medium," and less than 0.3 as "low." These quantitative findings were further supported by qualitative observation data, which provided insight into student engagement, participation, and higher-order thinking behaviors throughout the classroom activities.

▪ RESULT AND DISSCUSSION

Innovative Science Teaching Material

The development of the innovative science instructional module in this study was guided by the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). This model is widely recognized for its systematic yet flexible process in instructional development (Branch, 2009). Each stage generated specific outcomes that collectively strengthened the validity and effectiveness of the final product.

During the analysis phase, a needs assessment was conducted through classroom observations, curriculum analysis, and questionnaires for both students and teachers. Findings revealed that over 70% of students had difficulty understanding classification concepts due to the predominantly textual nature of existing materials and the lack of visual aids. Furthermore, 65% of teachers indicated the need for contextual teaching materials that incorporate inquiry-based activities to foster students' critical thinking. These findings align with Sari (2019), who emphasized that accurate needs analysis ensures that instructional products address real classroom challenges.

Based on the analysis, the instructional design was developed in the form of a storyboard and flowchart. The design integrated constructivist learning principles, particularly Vygotsky's scaffolding and Ausubel's meaningful learning. The content was structured progressively, beginning with simple classification activities and moving toward more complex analytical tasks. Contextual case studies drawn from students' daily environments were also embedded to enhance relevance. In line with Fajeriadi et al. (2024), a systematic and progressive design can significantly increase both motivation and higher-order thinking skills in science learning.

In the development phase, the draft module was produced in both digital and print-based formats. Expert validation was carried out by three validators (two subject-matter experts and one instructional design expert) using a rubric adapted from Nieveen (2007) and Akker (2010). The rubric assessed content relevance, material presentation, language clarity, visual support, and classroom applicability. Validation results indicated an average score of 3.7 out of 4 (92.5%), placing the product in the "highly valid" category (Table 1). This demonstrates strong content fidelity and practical feasibility, consistent with Plomp and Nieveen (2013), who highlight the critical role of expert validation in educational design research.

The validated module was implemented with a group of 30 seventh-grade students. Classroom trials revealed that 85% of students responded positively, especially in terms of clarity of instructions and contextual relevance. A pretest–posttest comparison demonstrated a statistically significant improvement in the experimental group's critical thinking skills compared to the control group ($p < 0.001$). These results support Hattie's (2008) findings that structured, learner-centered approaches significantly enhance learning outcomes.

The evaluation phase combined quantitative data (learning outcomes and N-Gain) with qualitative feedback from students and teachers. The average N-Gain score for the experimental group was 0.49, categorized as "moderate improvement" (Hake, 1999). Feedback also indicated that simplifying certain linguistic expressions and improving visual design could further enhance usability.

A learning instrument is considered valid when it effectively measures what it is designed to assess, aligning with instructional goals and relevant competencies. In this study, the validation process was conducted by three expert validators (two subject-matter experts and one instructional design expert), guided by a structured rubric adapted from Nieveen (2007) and Akker (2010). The rubric assessed five key aspects: content relevance, material presentation, language clarity, visuals and media, and classroom applicability. Each indicator was rated on a 4-point Likert scale. The results of this expert validation are summarized in Table 1.

Table 1. Validation results of learning instruments

Assessed Aspect	Maximum Score	Average Score	Percentage (%)	Validity Category
Content relevance	4	3.8	95%	Highly valid
Material presentation	4	3.7	92.5%	Highly valid
Language	4	3.6	90%	Highly valid
Visuals & supporting media	4	3.7	92.5%	Highly valid
Classroom applicability	4	3.8	95%	Highly valid
Overall average	–	**3.7**	**92.5%**	**Highly valid**

All assessed aspects reached the "highly valid" category, with an overall average score of 3.7 out of 4. This indicates strong alignment with instructional standards and practical applicability. Among the evaluated components, content relevance and classroom applicability scored the highest (95%), reflecting the material's alignment with curriculum indicators and its feasibility for real classroom use. These two aspects are crucial in bridging theoretical instructional design with actual learning environments (Akker, 2010; Plomp & Nieveen, 2013).

Although the language aspect also fell within the "highly valid" category (90%), its relatively lower score suggests room for refinement. Validator feedback highlighted instances of ambiguous phrasing and overly complex sentences that could potentially hinder comprehension, especially among students with lower reading proficiency. This finding points to the need for further revision, particularly in simplifying sentence structure and refining word choice to ensure accessibility (MoEC, 2008).

Furthermore, visual and media elements were judged as well-integrated and supportive of conceptual clarity, in line with Mayer's (2009) multimedia principles. However, future iterations could include student feedback on visual appeal and usability to enhance media effectiveness further.

Instead of simply reiterating numeric scores, these findings underline key instructional design considerations, namely the importance of content fidelity, linguistic accessibility, and implementation practicality. This multidimensional validation process ensures that the teaching materials are not only theoretically sound but also pedagogically impactful.

The development of the science instructional module in this study is grounded in constructivist learning theories, as outlined by Vygotsky (1978) and Ausubel (1968), which have been systematically integrated into the design of materials and learning activities. Vygotsky's concept of scaffolding is applied through graduated tasks that provide step-by-step guidance, enabling students to move from their actual development zone toward their zone of proximal development (Van de Pol et al., 2010). In the module, this is manifested by organizing tasks starting from simple observation and classification to complex analysis supported by examples and sufficient instructions. This scaffolding approach proved effective in improving students' critical thinking skills, as evidenced by the significant posttest score increases in the experimental group.

Ausubel's principle of meaningful learning is implemented by connecting the classification material to students' local context and everyday experiences, thereby strengthening the integration of new concepts into students' existing cognitive structures (Novak, 2010). The module utilizes case studies and familiar real-world objects, such as items and phenomena around home and school environments, making the material more relevant and easier to understand. This study supports previous findings showing that contextual learning significantly enhances students' motivation and comprehension (Maican et al., 2024).

The systematic and progressive structure of the module, aligned with Ausubel’s theory, also facilitates active student engagement and reflection, supporting the development of higher-order thinking skills. This is reflected in students’ positive responses to challenging and relevant materials, as well as the N-gain analysis indicating a moderate improvement in critical thinking skills (Hake, 1999). The following table summarizes the implementation of learning theories and their relationship to research findings.

Table 2. Theoretical foundations and their application in instructional design and research findings

Theoretical Principle	Implementation in Module	Research Findings
Vygotsky – Scaffolding	Graduated activities with stepwise guidance	Significant posttest score improvement in the experimental group ($p < 0.001$)
Vygotsky – Zone of Proximal Development	Cognitive support aligned with students’ readiness	Positive student responses to scaffolding and reflection
Ausubel – Meaningful Learning	Connecting material to experience and local context	Increased motivation and comprehension through contextual content
Ausubel – Material Organization	Systematic and progressive content structure	Active student engagement and improved critical thinking skills

This study confirms that integrating learning theories with contextual instructional design practices not only strengthens the theoretical validity of the materials but also significantly enhances their pedagogical effectiveness. As Hattie (2008) highlights, learner-centered and well-structured approaches support optimal learning outcomes, especially in developing critical thinking skills, which are key competencies of the 21st century.

Effectiveness of Innovative Science Teaching Materials

The findings of this study indicate a significant improvement in students' critical thinking skills as a result of using the innovative science instructional materials. This improvement is evident from the comparison between the average pretest and posttest scores of the experimental and control groups. In the experimental group, which consisted of 30 students, the average pretest score was 58.3. After the implementation of the innovative instructional materials, the average posttest score increased to 78.7, reflecting a gain of 20.4 points. This improvement is considered practically significant. In contrast, the control group, also consisting of 30 students, showed an increase in average scores from 57.9 (pretest) to 65.1 (posttest), with a difference of 7.2 points, which is not considered practically significant.

Furthermore, the results of the paired sample t-test support this finding. In the experimental group, the difference of 20.4 points yielded a t value of 9.624 with a significance level (Sig. 2-tailed) of less than 0.001 ($p < 0.05$), indicating a statistically significant improvement. In the control group, the 7.2-point increase yielded a t-value of

1.843 and a significance level of 0.075. Since the p-value exceeds 0.05, the improvement in the control group is not statistically significant. Therefore, these results demonstrate that the use of innovative science instructional materials had a substantial and statistically significant impact on enhancing students' critical thinking skills compared to conventional instruction.

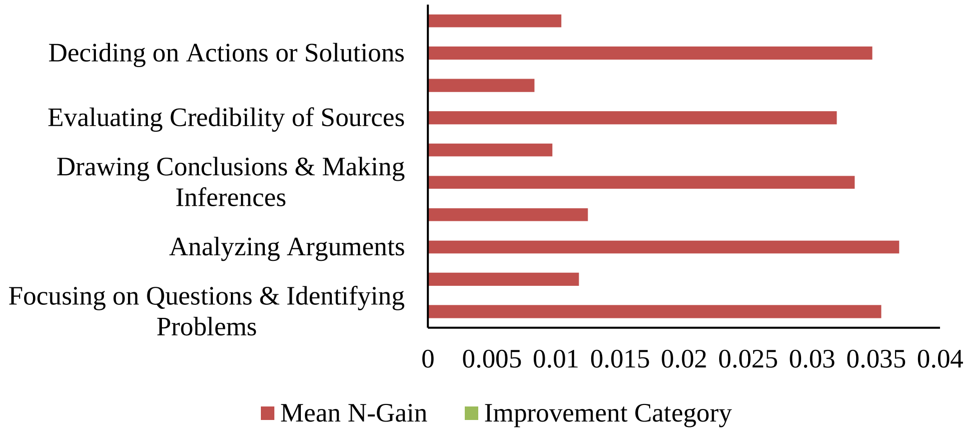


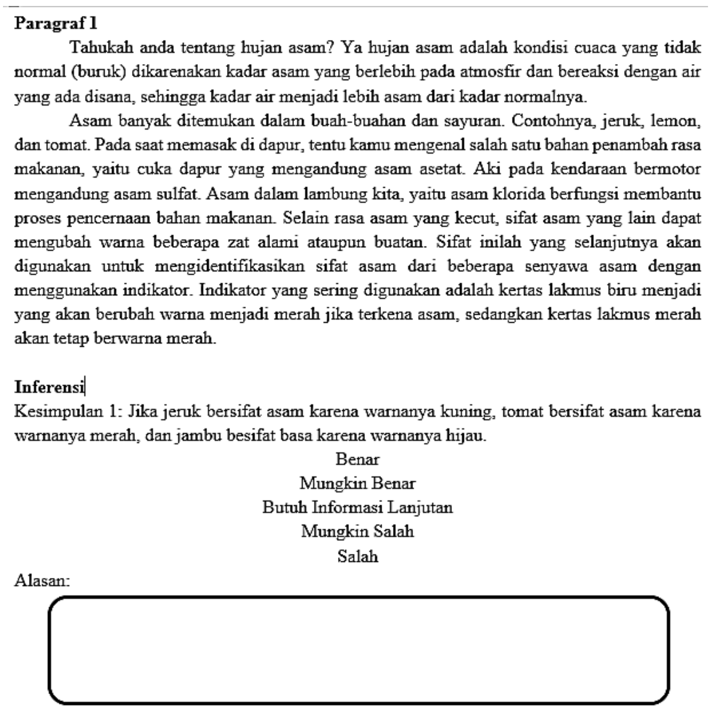
Figure 2. Comparison diagram of n-gain scores between the experimental group and the control group on each critical thinking indicator

In the experimental group, which was taught using the developed instructional materials, the average pretest score was 58.3, and the posttest score increased to 78.7, representing a gain of 20.4 points. This increase was statistically significant ($p < 0.001$) based on the paired sample t-test, indicating a high level of effectiveness. In contrast, the control group, which received conventional instruction, showed a modest and statistically insignificant gain from 57.9 to 65.1 points ($p = 0.075$).

Further item-level analysis of the pretest–posttest results in the experimental group revealed that the most significant improvements occurred in the indicators of analysis and evaluation. Students demonstrated increased ability to distinguish relevant attributes when classifying objects (analysis), and to justify their classification decisions with logical arguments, even when presented with contradictory or ambiguous data (evaluation). For instance, average scores for analysis-based items increased from 55.0 to 80.4, and for evaluation-based items, from 56.7 to 79.2. Improvements in inference and interpretation were also observed, but the gains were slightly lower compared to the other indicators.

These findings suggest that the instructional materials were particularly effective in promoting higher-order cognitive skills that involve comparing, assessing, and drawing reasoned conclusions, core aspects of critical thinking as defined by Facione (2015) and Ennis (2011). The structured learning activities, such as reflective questions, open-ended classification tasks, and guided discussions, appeared to directly support students' development in these areas.

The observed learning gains in the experimental group are directly attributed to the structure and features of the innovative materials, which were specifically designed to stimulate critical thinking. These materials included problem-based activities, local-contextual case studies (object classification in real-world environments), visual aids such as concept maps, and reflection prompts that required students to justify their reasoning. Instructional tasks were framed around core critical thinking indicators as defined by Facione (2015), namely analysis, inference, evaluation, and explanation, and also reflected the dispositions and abilities emphasized by Ennis (2011).



Paragraf 1

Tahukah anda tentang hujan asam? Ya hujan asam adalah kondisi cuaca yang tidak normal (buruk) dikarenakan kadar asam yang berlebih pada atmosfir dan bereaksi dengan air yang ada disana, sehingga kadar air menjadi lebih asam dari kadar normalnya.

Asam banyak ditemukan dalam buah-buahan dan sayuran. Contohnya, jeruk, lemon, dan tomat. Pada saat memasak di dapur, tentu kamu mengenal salah satu bahan penambah rasa makanan, yaitu cuka dapur yang mengandung asam asetat. Aki pada kendaraan bermotor mengandung asam sulfat. Asam dalam lambung kita, yaitu asam klorida berfungsi membantu proses pencernaan bahan makanan. Selain rasa asam yang kecut, sifat asam yang lain dapat mengubah warna beberapa zat alami ataupun buatan. Sifat inilah yang selanjutnya akan digunakan untuk mengidentifikasikan sifat asam dari beberapa senyawa asam dengan menggunakan indikator. Indikator yang sering digunakan adalah kertas lakmus biru menjadi yang akan berubah warna menjadi merah jika terkena asam, sedangkan kertas lakmus merah akan tetap berwarna merah.

Inferensi

Kesimpulan 1: Jika jeruk bersifat asam karena warnanya kuning, tomat bersifat asam karena warnanya merah, dan jambu besifat basa karena warnanya hijau.

Benar
Mungkin Benar
Butuh Informasi Lanjutan
Mungkin Salah
Salah

Alasan:

Figure 3. Examples of inference questions in critical thinking instruments

More specifically, student improvements aligned with key indicators of critical thinking. For instance, the ability to analyze was fostered through tasks that required distinguishing relevant object characteristics, while inference was encouraged as students made generalizations and predicted classifications based on patterns. The task of justifying classifications required evaluation and explanation, as students were prompted to support their conclusions with logical arguments. The consistent improvement in posttest performance suggests that the materials effectively guided students through these higher-order thinking processes. To measure critical thinking, the pretest and posttest instruments consisted of multiple-item essay tests and performance-based tasks that were validated through expert review. Items required students to:

1. Compare and contrast objects based on observable and inferred attributes.
2. Construct classification schemes using scientific criteria.
3. Justify classifications using logical reasoning.
4. Evaluate and revise their initial decisions when presented with contradictory data.

An example test item included: "Given a set of ten objects, classify them into appropriate categories based on more than one characteristic (physical properties, source, function). Explain the reasoning behind each classification and identify any objects that could fit into multiple categories."

The effectiveness of the materials, therefore, lies not only in their validity as instructional products but also in their alignment with authentic, higher-order learning outcomes. These results reinforce the premise that instructional materials grounded in constructivist and contextual principles are more likely to engage students cognitively and promote deeper understanding (Zohar & Dori, 2003).

Similar findings have been reported in previous studies focusing on the use of higher-order thinking skills (HOTS) in science education. For instance, Rahmawati et al. (2021) demonstrated that contextual science tasks that involve classification activities improved students' ability to analyze and evaluate biological phenomena. Likewise, research by Shalihah et al. (2023) on HOTS-oriented biology modules reported significant gains in students' skills to compare, infer, and justify classification criteria. These studies support the notion that object classification, when presented through guided inquiry and reflective questioning, provides a concrete and accessible entry point for developing students' critical thinking.

However, unlike prior studies that generally emphasize either content understanding or inquiry learning separately, the current study integrates classification tasks with explicitly designed scaffolds targeting analysis, inference, and evaluation indicators. This dual focus on both content mastery and critical thinking performance represents a more holistic instructional approach that is still relatively rare in the existing literature.

Moreover, the study highlights the importance of testing both content validity and empirical effectiveness, as recommended by Nieveen (2007) and Plomp & Nieveen (2013). The instructional design successfully bridged theoretical understanding with classroom realities, offering teachers a practical tool to foster 21st-century competencies.

The Kolmogorov–Smirnov test was employed to evaluate the normality of the critical thinking test score data. As shown in Table 9, both the experimental and control groups produced significance values greater than 0.05 (0.126 and 0.084, respectively), indicating that the data from both groups are normally distributed. This normal distribution satisfies the assumptions required for subsequent parametric analyses, such as the paired sample t-test and independent sample t-test (Ghozali, 2016).

Table 3. Results of normality test and improvement of critical thinking skills scores based on n-gain test for each indicator

Indicator	Group	N	Mean N-Gain	Improvement Category
Focusing on Questions & Identifying Problems	Experimental	30	0.51	Medium
	Control	30	0.17	Low
Analyzing Arguments	Experimental	30	0.53	Medium
	Control	30	0.18	Low
Drawing Conclusions & Making Inferences	Experimental	30	0.48	Medium
	Control	30	0.14	Low
Evaluating Credibility of Sources	Experimental	30	0.46	Medium
	Control	30	0.12	Low
Deciding on Actions or Solutions	Experimental	30	0.50	Medium
	Control	30	0.15	Low

Note: Improvement categories according to Hake (1999)

- High: ≥ 0.7

- Medium: 0.3 – 0.69
- Low: < 0.3

To assess the magnitude of learning improvement, the normalized gain (N-Gain) was calculated by comparing the increase in individual student scores with the maximum possible improvement that could be achieved. The experimental group demonstrated a mean N-Gain of 0.49, categorized as medium, whereas the control group achieved only 0.15, classified as low. These values reflect the relative progress made by students in each group based on their initial understanding.

This means the student achieved 50% of the possible improvement. A 0.49 average gain across the experimental group signifies that most students achieved nearly half of their maximum potential increase in critical thinking scores, an outcome considered pedagogically meaningful.

The low N-Gain of 0.15 in the control group suggests minimal advancement, likely representing incidental improvement rather than systematic instructional impact. This contrast supports the conclusion that the use of innovative instructional materials characterized by contextual learning scenarios, structured tasks encouraging analysis and evaluation, and guided inquiry significantly enhances students' critical thinking capabilities.

In alignment with educational design principles, the use of N-Gain as a metric highlights not only the post-intervention outcomes but also the learning trajectory enabled by the instructional innovation. These findings reinforce earlier results from the paired sample t-test and align with prior research emphasizing the value of innovative materials in promoting deep cognitive engagement (Facione, 2015).

Furthermore, this result affirms the dual validity of the instructional product: it is both content-valid and pedagogically effective. According to the design-based research (DBR) framework, such dual validation through expert review and real-classroom implementation is essential to ensure the feasibility and impact of educational innovations (Plomp & Nieveen, 2013). To evaluate user perceptions and affective responses, a questionnaire was administered to students after using the innovative science teaching material. The aim was to gather feedback on aspects such as visual design, clarity, contextual relevance, and cognitive stimulation.

Table 4. Students' questionnaire results on the teaching material

No	Assessment Aspect	Maximum Score	Average Score	Percentage (%)	Category
1	Visual appeal	4	3.6	90%	Excellent
2	Ease of understanding	4	3.5	87.5%	Excellent
3	Relevance to real-life contexts	4	3.6	90%	Excellent
4	Enhancement of thinking skills	4	3.4	85%	Excellent
	Overall average	**–**	**3.525**	**88.4%**	**Excellent**

The results demonstrate an overall average score of 3.525 out of a maximum of 4, corresponding to an 88.4% approval rate, which falls into the excellent category. These findings indicate strong student approval of the teaching material. Among the individual aspects, visual appeal received the highest average score (3.6 or 90%), suggesting that the design was visually engaging and contributed to students' attention and focus. This finding supports Mayer's (2009) multimedia learning theory, which emphasizes the role of well-designed visuals in enhancing cognitive processing.

The ease of understanding score (3.5 or 87.5%) indicates that students found the material comprehensible and appropriately matched to their developmental stage. This aligns with Brookhart's (2010) emphasis on instructional clarity as a foundation for effective learning.

The aspect of relevance to real-life contexts also scored 3.6 (90%), suggesting that students were able to relate the content to their daily lives or local environment. For example, some students in open-ended responses noted that “the examples in the module remind us of the plants and rivers near our home,” or that “we often see the situations explained, so it is easier to understand.” These responses affirm the successful integration of contextual learning principles (Johnson, 2002).

While still within the excellent range, enhancement of thinking skills received the lowest score (3.4 or 85%). This suggests that, although students perceived the material as encouraging deeper thinking, this aspect could be further strengthened. Some students expressed in open responses that “the tasks are helpful, but could ask more challenging questions” or “more activities that make us compare things would be better.” These reflections point to the need for greater inclusion of open-ended and higher-order thinking tasks, such as evaluative questions, argument building, or problem-solving scenarios, to deepen students’ cognitive engagement.

In summary, the student feedback validates the usability and appeal of the teaching material while also providing insights for future refinement—particularly in enhancing its capacity to promote critical and reflective thinking. This form of user validation plays a critical role in R&D-based instructional material development, as emphasized by Borg and Gall (2003), who advocate for incorporating user experience to ensure contextual fit and effectiveness.

This study contributes significantly to the field of science education, particularly in strengthening learning theories grounded in constructivism and the promotion of critical thinking skills. The findings reveal that the use of science teaching materials designed with contextual content and visual elements can meaningfully improve students’ critical thinking abilities. This outcome aligns with Vygotsky's (1978) theory of scaffolding and the zone of proximal development, which emphasizes the importance of appropriate instructional support in advancing cognitive development. Similarly, the results support Ausubel's (1968) principle of meaningful learning, which highlights that learners construct understanding more effectively when new content is connected systematically to their prior knowledge and real-world experiences.

From a practical perspective, the study provides evidence-based guidance for junior high school science teachers in selecting or developing teaching materials. Rather than focusing solely on content accuracy, effective materials must also consider visual appeal, ease of understanding, and relevance to students’ real-life contexts—three aspects that have been demonstrated to enhance engagement and learning outcomes. The developed teaching material, validated through expert judgment and field implementation, emerges as a viable alternative to traditional learning media that supports the scientific approach and the development of 21st-century competencies, especially critical thinking.

The novelty of this research lies in two primary innovations. First, it integrates local contextual elements into the instructional design, which is still limited in prior studies focusing on generic or textbook-centered content. This local grounding allows learners to relate more directly to the material, potentially increasing conceptual retention and engagement. Second, the study employs a dual validation approach, involving both expert review and student feedback, as well as empirical effectiveness testing using statistical methods such as paired sample t-tests and N-gain analysis. This comprehensive methodology strengthens the internal and external validity of the research outcomes.

Scientifically, this research offers robust evidence that contextual and visually rich teaching materials can serve as effective interventions to enhance critical thinking, an enduring challenge in science education, particularly within the Indonesian junior high school context. The study's contributions are also relevant for curriculum developers and module designers, as it emphasizes the value of scientific literacy and context-based problem solving as instructional goals.

However, this study is not without limitations. The research was conducted within a limited geographical and demographic scope, potentially affecting the generalizability of the findings. Additionally, the study focused solely on critical thinking outcomes; other cognitive or affective dimensions such as creativity, scientific reasoning, or student motivation were not explored in depth. Future research is encouraged to examine the broader impacts of such teaching materials, including their long-term effects and application across diverse subject areas and student populations.

In conclusion, this study enriches both theoretical understanding and practical approaches in science education by providing a replicable model of how contextualized, visually engaging, and validated instructional materials can effectively support students' higher-order thinking skills. It opens opportunities for continued innovation in material development that is not only pedagogically sound but also culturally and contextually relevant.

▪ CONCLUSION

The innovative science instructional material developed in this study demonstrated high validity, with an average expert validation score of 92.5%, covering essential aspects such as content relevance, clarity of presentation, language use, visual design, and classroom applicability. The empirical implementation of the material led to a statistically significant improvement in students' critical thinking skills on the topic of object classification, with the experimental group showing a mean gain of 20.4 points ($p < 0.001$) between the pretest and posttest, compared to an insignificant increase in the control group. The calculated N-Gain score of 0.49 in the experimental group indicates a moderate level of effectiveness, while the control group's score of 0.15 falls into the low category. These findings suggest that the instructional material has meaningful potential in enhancing students' higher-order thinking.

In addition to the quantitative results, students responded positively to the instructional material, with an average satisfaction score of 88.4% across dimensions such as visual appeal, ease of understanding, real-life relevance, and thinking skill enhancement. These affective responses underscore the material's practical usability and acceptance in classroom settings.

This study contributes theoretically by redefining object classification—not merely as a content topic, but as an entry point for developing core components of critical thinking, such as analysis and evaluation. The design process combined structured learning activities with contextual and visual elements to actively engage students in higher-order thinking. The integration of validation and classroom testing also adds novelty by linking theoretical design with practical classroom impact.

Although promising, these findings are limited by the study's narrow scope and specific context. Future research should explore broader applications and long-term effects of the material across different subjects and learner profiles. Therefore, while the developed teaching material is shown to be moderately effective and well-received in junior high school science education, particularly in teaching the topic of object classification, it is most suitable for implementation in classroom environments that support student-centered, contextual learning and where teachers are familiar with using innovative, visual-based resources. Future studies are recommended to expand the research across different content topics, grade levels, and learning outcomes, and to assess long-term impacts and scalability of the instructional approach.

▪ RECOMMENDATION

Based on the research findings, it is recommended that junior high school science teachers incorporate the developed innovative instructional material as a supplementary learning resource, especially when aiming to improve students' critical thinking skills in topics that require analysis and classification, such as "classification of objects." To maximize its impact, the material should be integrated into teacher training programs and professional development workshops, enabling educators to effectively adapt and apply context-based and visually enriched teaching strategies in the classroom.

For future developers and researchers, it is advisable to further enhance the instructional material by incorporating specific learning components aimed at developing creativity, scientific argumentation, and students' scientific attitudes. While the current study focused on critical thinking, the positive student reception and moderate learning gains suggest potential for broader cognitive and affective outcomes. These enhanceents should be empirically tested in future studies to ensure their relevance and impact.

Moreover, it is strongly recommended to pilot the teaching material across different subjects (e.g., biology, physics) and educational levels (elementary or high school) to evaluate its transferability and scalability of effectiveness. Such cross-context testing would provide valuable insights into the robustness and adaptability of the design model.

Lastly, schools and educational policymakers should consider supporting the integration of context-based, student-centered teaching materials into the curriculum. This can be achieved by investing in the development of digital learning platforms, allocating time and resources for teacher collaboration in instructional design, and promoting policies that emphasize 21st-century skills, such as critical thinking, creativity, and scientific literacy.

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