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Development of a STEAM-Based Module to Enhance HOTS (Analytical, Critical, and Creative Thinking) for Pre-service Science Teachers at UNISLA

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Abstract

The demand for adaptive graduates in the Society 5.0 era necessitates the enhancement of Higher-Order Thinking Skills (HOTS). However, this is constrained by a lack of innovative teaching materials for pre-service science teachers at the Islamic University of Lamongan. This research aims to develop and assess the feasibility and effectiveness of a STEAM-based module designed to improve HOTS (analytical, critical, and creative thinking). Employing a 4D model of Research and Development (R&D), the product was validated by six experts and trialled with 25 students using a one-group pretest/posttest design. Data were analyzed using feasibility percentages and N-Gain scores. The results indicated that the module was declared "Very Feasible" by the experts, with scores of 88% for material content, 85.8% for language, and 90% for media. The module's implementation proved effective, achieving an average N-Gain score of 0.78 (categorized as "High"). This included improvements in creative thinking (N-Gain 0.85), critical thinking (N-Gain 0.78), and analytical thinking (N-Gain 0.69). Furthermore, the module received a highly positive response from students (89.2%). Therefore, this STEAM-based learning module is proven to be a valid and effective practical solution for enhancing the multiple dimensions of HOTS among pre-service teachers and can serve as a model for developing instructional materials in higher education.

INTRODUCTION

Success in the Society 5.0 era is significantly determined by the preparedness of human resources, which are fostered through education [1]. Education plays a crucial role in developing adaptive human resources capable of addressing contemporary challenges by shaping individuals who possess mastery of relevant knowledge and skills [2]. In alignment with this, the Indonesian government has established a national research focus on creating a competitive education system and enhancing the quality of higher education graduates. In this context, university students are not only required to possess an academic degree but must also be equipped with 21st-century skills. One of these fundamental skills is Higher-Order Thinking Skills (HOTS), which encompasses analytical, critical, and creative thinking [3], [4]. These skills, which also include problem-solving and decision-making [5], have been shown to enable students to comprehend complex concepts and solve problems effectively [6].

To enhance students' Higher-Order Thinking Skills (HOTS), innovative learning approaches such as STEAM (Science, Technology, Engineering, Arts, and Mathematics) are believed to provide significant stimulation [7]. The STEAM approach has become a focal point in education due to its ability to holistically integrate various disciplines. This integration enables students to connect their knowledge across different fields, perceive the interconnections between concepts, and ultimately enhance their creativity in problem-solving [8], [9]. This approach makes learning more engaging and relevant to the real world, as students are encouraged to explore, experiment, and innovate through integrated projects [10].

Although several studies have demonstrated the positive impact of the STEAM approach, they have limitations, as many focus on primary or secondary education levels. A crucial research gap is the lack of comprehensive and validated STEAM-based teaching materials specifically designed for pre-service teachers at the higher education level in a specific course. Therefore, the novelty of this research lies in developing teaching materials that integrate an innovative learning model with the STEAM approach, as well as analyzing its effectiveness specifically in enhancing the HOTS of pre-service science teachers.

The need for developing innovative higher education teaching materials becomes increasingly crucial when considering the specific conditions at the Science Education Study Program at the Islamic University of Lamongan [11]. A preliminary needs analysis revealed a significant problem: both students and lecturers expressed an urgent need for more varied teaching materials for the Innovative Learning course, for which reference sources are still limited. This is reinforced by the fact that learning tends to be lecturer-centred, which 52.6% of students acknowledged as inadequate for in-depth understanding. This condition ultimately impacts the low level of students' HOTS, as evidenced by pretest results that did not align with the expected indicators.

The gap between the demand for HOTS competencies for pre-service science teachers and the availability of supportive, innovative, and effective teaching materials at Unisla creates a clear research problem. Teaching materials themselves offer significant benefits for learning achievement as they present structured content that outlines the skills to be mastered [12]. Therefore, this research aims to develop valid and effective higher education teaching materials to enhance the HOTS of pre-service science teachers by integrating an innovative learning model with the STEAM approach. Specifically, this study aims to address three primary questions. First, what is the validity level of the STEAM-based teaching materials, as judged by experts, in terms of content, language, and media aspects? Second, how effective is the implementation of these teaching materials in improving the HOTS (analytical, critical, and creative thinking) of pre-service science teachers. Third, what are the student responses to the use of STEAM-based teaching materials.

METHODS

This study employed a Research and Development (R&D) approach, adapting the 4D model, which consists of four main stages: Define, Design, Develop, and Disseminate. To test the effectiveness of the developed instructional materials, a field trial was conducted using a One-Group pretest and posttest design. The overall research flow is visualized in the diagram in Figure 1. Operationally, each stage in the 4D model was implemented as follows:

1. Define Stage: This stage involved identifying problems and needs in the field, which included an analysis of the availability of instructional materials, a needs assessment of students and lecturers, an examination of student characteristics, and an evaluation of concepts and materials relevant to the Innovative Learning course.
2. Design Stage: This stage focuses on designing the initial product of the instructional materials by determining the learning outcomes, formulating specific Higher-Order Thinking Skills (HOTS) indicators (analytical, critical, and creative), and designing the appropriate media specifications, language, and materials for students.
3. Development Stage: The product was developed through expert validation and revised based on the feedback received. The validated product was then pilot-tested on a limited scale.
4. Dissemination Stage: The proven-effective product was implemented on a broader scale, and student feedback was gathered for the final evaluation.

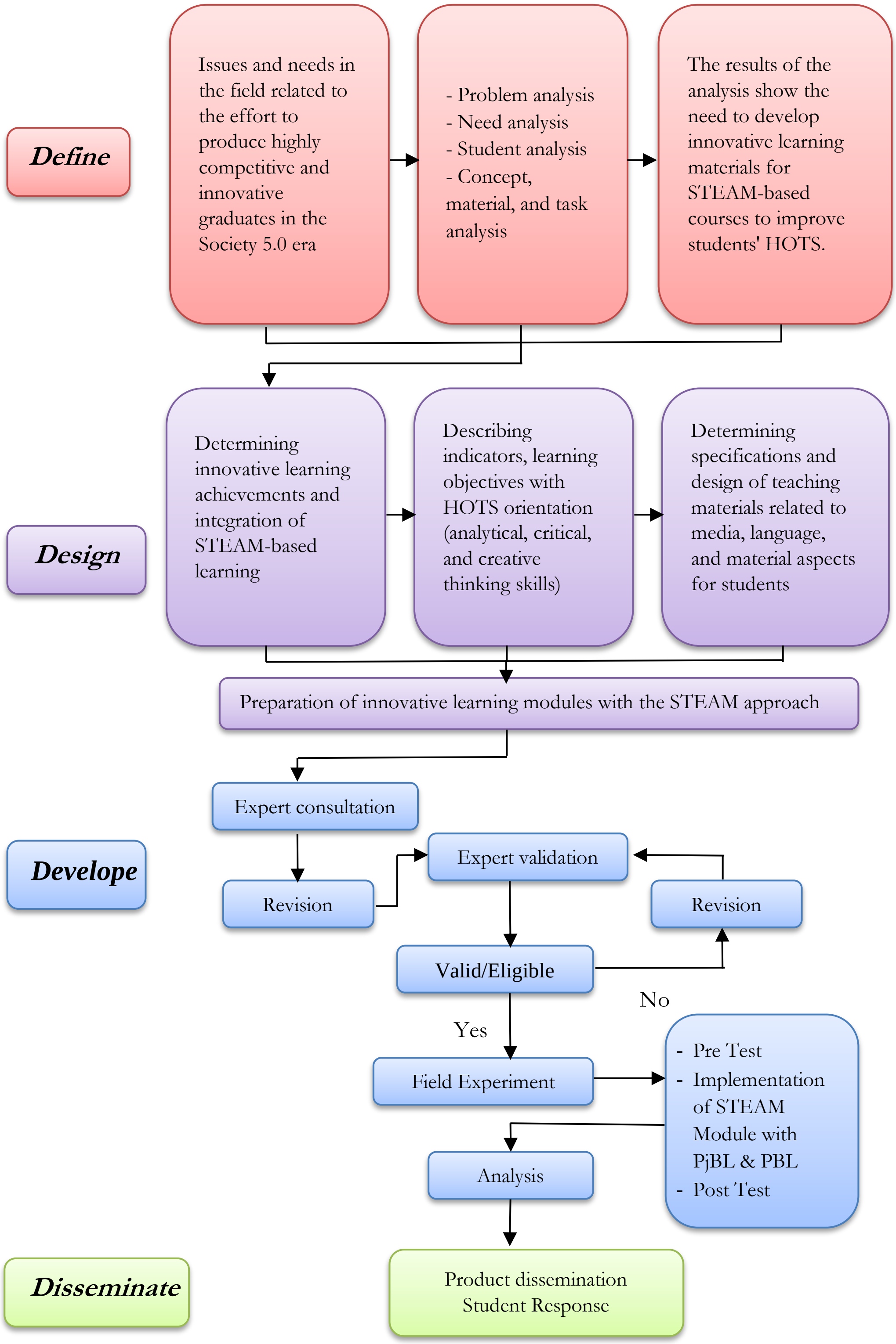


Figure 1. 4D model research flowchart

This research involved two primary groups of participants: expert validators for assessing product feasibility and students for a field trial. The validation phase involved a panel of six faculty experts selected based on their relevant expertise. This panel included two experts in Science Education content, two in the Indonesian language, and two in instructional media development. Subsequently, the field trial was administered to 25 students from the Science Education Study Program at Unisla. The inclusion criterion stipulated that participants must be active third-semester students enrolled in the mandatory "Innovative Learning" course. No exclusion criteria were applied based on other demographics, such as age or gender.

Data were collected using two types of instruments: test and non-test. Non-test instruments, in the form of observation sheets and questionnaires, were utilized during the pre-research phase for expert validation and to ascertain student responses. The test instrument, conversely, comprised essay questions containing items related to analytical thinking skills, critical thinking skills, and creative thinking skills to measure the improvement in students' HOTS. The analysis of data from the lecturer validation of the developed product and student responses utilized the average score for each assessment criterion/indicator, as per equation (1):

$$\overline{X} = \frac{\sum x}{n} + 100\% \quad (1)$$

$\overline{X}$ = mean score
$\sum x$ = total sum of scores from each assessor
n = number of assessors

Subsequently, the percentage feasibility scores from the validator assessment results are categorized as shown in Table 1:

Table 1. Feasibility criteria for validation results

Score	Criteria
0-20	Very infeasible
21-40	Infeasible
41-60	Fairly feasible
61-80	Feasible
81-100	Very feasible

Meanwhile, the improvement in students' HOTS is measured using the N-Gain formula developed by Richard R. Hake, which is used to calculate the normalized gain between pretest and posttest scores, as shown in equation (2):

$$\text{N} - \text{Gain} = \frac{S_{post\ test} - S_{pre\ test}}{S_{maks} - S_{pre\ test}} \quad (2)$$

Subsequently, the obtained N-Gain scores are categorized according to the criteria in Table 2.

Table 2. N-Gain score criteria

N-Gain Category	Criteria
N-gain > 0,7	High
0,3 ≤ N-gain ≤ 0,7	Medium
N-gain ≤ 0,3	Low

The effectiveness of the implemented instructional materials can be measured by the N-gain percentage value, as categorized in Table 3, adapted from [13]:

Table 3. N-gain effectiveness categories

N-gain Category (%)	Description
< 40	Ineffective
40-55	Less effective
56-75	Moderately effective
> 76	Effective

Furthermore, the percentage scores of student responses are categorized as shown in Table 4:

Table 4. Student response criteria

Score	Criteria
0-20	Very unattractive
21-40	Unattractive
41-60	Fairly unattractive
61-80	Attractive
81-100	Very attractive

The researchers stipulated that this study's success is achieved if the validation results indicate "feasible" and "very feasible" outcomes; if, during the field trial, students' HOTS improves as indicated by N-Gain scores falling into the "medium" and "high" categories; if effectiveness is categorized as "moderately effective" or "effective"; and if student responses meet the "attractive" and "very attractive" criteria.

RESULTS AND DISCUSSION

These research findings are objectively and systematically presented, beginning with the validation and feasibility results of the instructional materials, followed by a quantitative analysis of its impact on Higher-Order Thinking Skills (HOTS), and concluding with students' perceptions of the learning experience. This data is presented to provide a clear and measurable overview of the intervention's outcomes before an in-depth interpretation in the discussion section.

Validation and Feasibility of STEAM-Based Teaching Materials

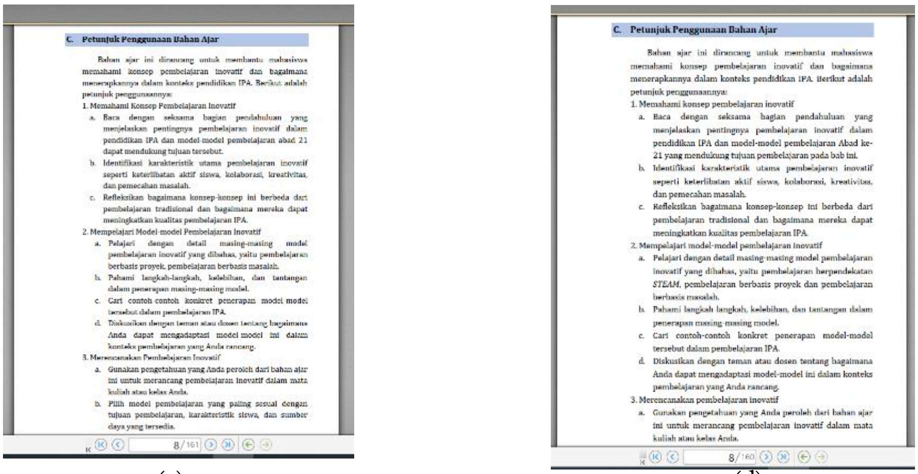
The development process of the teaching materials adheres to a research and development framework that involves expert validation to ensure the product's feasibility before implementation. This validation is a crucial stage to ensure that the teaching materials are not only conceptually innovative but also robust in terms of content, language, and media presentation. Quantitative data from the validation process indicate a high level of feasibility. Based on the assessment conducted by six experts—comprising two science content experts, two language experts from Indonesian Language Education, and two learning media experts—the developed teaching materials achieved an average feasibility score of 88%. According to the established criteria, this score places the teaching materials in the 'Very Feasible' category for implementation in the learning process at the higher education level.

In addition to the quantitative assessment, qualitative feedback from the validators served as the basis for iterative product revisions. This refinement process reflects a commitment to quality and responsiveness to expert review. The main revisions undertaken addressed three fundamental aspects. First, enhancements were made to the cover design, name, and logo (Figure 1) to improve visual appeal and ensure an accurate and engaging representation of the content. Second, the restructuring of the organizational framework and user guide (Figure 2 in the original manuscript) aimed to improve the logical flow, readability, and ease of navigation for students. Third, improvements to table layouts and the integration of visual elements (Figure 3 in the original manuscript) were implemented to facilitate data comprehension and present complex information more intuitively.

The following are some visual examples from the developed teaching materials:

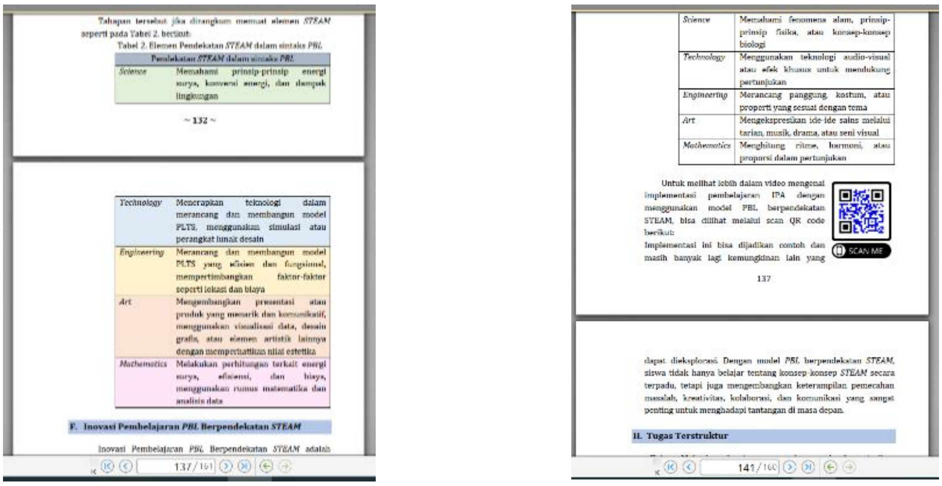
(a) (b)

Figure 1. Revision of the developed teaching material's cover: (a) before revision and (b) after revision.



(c) (d)

Figure 2. Revisions to the writing and organization of the teaching material's instructions: (c) before revision and (d) after revision.



(e) (f)

Figure 3. Revisions to the table and layout: (e) before revision and (f) after revision.

The Impact of the Intervention on Higher-Order Thinking Skills (HOTS)

To measure the effectiveness of the STEAM-based teaching materials on improving students' HOTS, a measurement was conducted using a pretest and posttest design with 25 students from the Science Education study program who were the subjects of the research. Descriptive statistical analysis indicated a substantial improvement in performance after the intervention. Table 5 summarises the central tendency and variability of the students' HOTS scores before and after using the teaching materials (module).

Table 5. Descriptive Statistics of Student HOTS Scores (N=25)

Score	Mean	Standard Deviation (SD)	Minimum	Maximum
Pretest	53.32	6.97	35	65
Posttest	82.44	4.31	76	91

The data in Table 5 shows a significant increase in the mean score, from 53.32 on the pretest to 82.44 on the posttest. Furthermore, the standard deviation decreased from 6.97 to 4.31, indicating that the student scores on the posttest became more homogeneous. This implies that the intervention not only improved overall performance but also tended to equalize the level of understanding among students. To visualize this change, the distribution of pretest and posttest scores can be presented in a box plot diagram, which illustrates an upward shift in the median and a narrowing of the interquartile range on the posttest scores.

The effectiveness of the intervention was further assessed using the normalized N-Gain score, which is designed to evaluate learning improvement by taking prior knowledge into account. The average N-Gain score for all participants was 0.78. According to the N-Gain interpretation criteria, this score falls into the 'High' category, confirming that the improvement was highly significant. The distribution of N-Gain categories among students reveals that the majority of participants experienced substantial improvement; 19 students (76%) achieved the 'High' category, while the remaining six students (24%) reached the 'Medium' category. It is worth noting that no students fell into the 'Low' category, which reinforces the consistent positive impact of the intervention.

For a more in-depth analysis, the HOTS data were disaggregated by their three primary dimensions: analytical thinking, critical thinking, and creative thinking. Table 6 provides the framework for this analysis, allowing for the identification of which dimensions showed the most significant improvement.

Table 6. Analysis of Pretest, Posttest, and N-Gain Scores by HOTS Dimension

HOTS Dimension	Mean Pretest Score	Mean Posttest Score	Mean N-Gain	N-Gain Category
Analytical Thinking	18.00	26.50	0.69	Medium
Critical Thinking	17.50	27.50	0.78	High
Creative Thinking	17.82	28.44	0.85	High

Note: The maximum score for each dimension is 33.33, based on a total ideal score of 100 equally divided among the three dimensions.

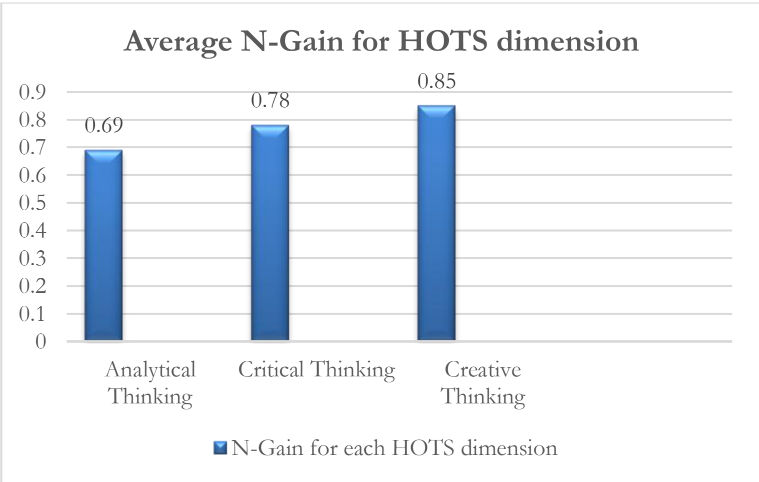


Figure 2. Comparison of the average N-Gain for each HOTS dimension

The diagram in Figure 2 compares the effectiveness of the increase (N-Gain) for each dimension, showing that creative thinking experienced the highest increase, followed by critical and analytical thinking.

Student Perceptions of the Learning Experience

The final stage of data collection involved measuring student responses to the implemented learning materials. This data provided insights into the end-users' perspectives on the appeal, usefulness, and overall learning experience. Quantitatively, the student response questionnaire results showed a mean score of 89.2%. This score indicates a 'Very Good' or 'Highly Positive' perception from the students regarding the learning materials and the instructional approach used. Further analysis of the qualitative data from students' open-ended responses revealed four consistent main themes. First, students generally reported that the learning process became more enjoyable and that they felt more actively involved. Second, the learning materials were perceived to effectively encourage them to think analytically, critically, and creatively in solving the presented problems. Third, students appreciated the opportunity to collaborate and discuss with their peers, which they felt enriched their understanding. Fourth, the learning was considered relevant to their future career needs and challenges as prospective educators, which enhanced their intrinsic motivation to learn.

The discussion is structured around four key areas: (1) an analysis of the overall and differential effectiveness of the STEAM teaching materials in enhancing HOTS; (2) the contextualization and comparison of the findings with relevant scientific literature; (3) a critical reflection on the study's methodological limitations; and (4) the implications of the findings for educational practice and recommendations for future research directions.

Effectiveness of STEAM Teaching Materials in Enhancing HOTS

The main finding of this study is a statistically significant increase in the HOTS scores of pre-service science teachers, rising from a pretest mean of 53.32 to a posttest mean of 82.44. This improvement is corroborated by a high average N-Gain score of 0.78. These data provide strong evidence that instructional materials developed by integrating the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach are effective in enhancing Higher-Order Thinking Skills. This increase indicates not only that students acquired new knowledge but also that they were able to apply more complex cognitive processes such as analysis, evaluation, and creation, which form the core of HOTS [3], [14], [15].

However, a deeper analysis reveals a more nuanced dynamic. The decrease in the standard deviation of scores, from 6.97 in the pretest to 4.31 in the posttest, indicates that the performance variability among students narrowed following the intervention. This is more than a mere statistic; it is a crucial pedagogical indicator. The intervention not only benefited students with high initial abilities but also effectively elevated the performance of their initially lower-achieving peers. In other words, the instructional materials fostered a more homogeneous understanding across the cohort, demonstrating the approach's potential to function as an equalizer that reduces the achievement gap within this specific classroom context.

Differential Analysis of HOTS Dimensions and the Role of Pedagogical Components

A differential analysis by HOTS dimensions, as outlined in the framework presented in Table 6, enables us to deconstruct the intervention and identify which components may be the most influential. Although the specific data for each dimension is to be supplied by the authors, we can hypothesize based on the design of the instructional materials, which integrate STEAM with Project-Based Learning (PjBL) and Problem-Based Learning (PBL). If creative thinking were to show the highest N-Gain, this could be logically attributed to two key elements. The first is the emphasis on the 'Arts' component within STEAM, which inherently fosters divergent thinking, aesthetics, and innovative design [7], [9], [16]. The second is the product-oriented nature of PjBL, where students are challenged to design and create tangible artifacts or real-world solutions [8]. The process of creating something new from learned concepts is a direct manifestation of creative thinking [9]. This finding would be consistent with the study by Maulidiansy et al. [17], who found that a STEAM-based interactive e-module was effective in enhancing student creativity.

Meanwhile, the improvement in critical thinking is driven by the structure of PBL. PBL commences with a complex, ill-structured problem, requiring students to analyze the issue, evaluate various information sources, and ultimately defend their proposed solution [15], [18]. This process directly trains evaluation and synthesis skills, which are cornerstones of critical thinking [3], [15]. Furthermore, the strong collaborative elements in both PjBL and PBL compel students to consider, challenge, and negotiate different perspectives—a crucial exercise in critical thought [8]. The enhancement of analytical thinking is likely honed in the initial stages of PBL, where students must break down an ambiguous problem into manageable components and researchable questions. The data analysis required to complete their projects further strengthens this skill.

The implications of this differential analysis are significant. It suggests that the various components within the intervention framework (STEAM, PjBL, PBL) do not contribute uniformly to all aspects of HOTS. Instead, they work synergistically with varying strengths. PjBL and the 'Arts' act as primary drivers for creativity, while PBL and its evaluative tasks are key drivers for critical thinking. This awareness of differentiated contributions allows educators to intentionally design or tailor their learning interventions to target the specific HOTS dimensions that are most relevant or most in need of improvement within their curriculum.

Situating the Findings within the Literature

To validate and comprehend the significance of these findings, it is essential to situate them in the context of existing research. The results of this study consistently reinforce several key trends within the educational literature. First, the findings align with previous research indicating that STEAM integration can significantly enhance 21st-century skills, including critical thinking and creativity (the 4Cs) [19]. Although their research contexts differed (e.g., integrating local wisdom), the similar outcomes underscore the robustness of the STEAM approach as a framework for cultivating higher-order competencies. Likewise, these results support the findings of Twiningsih and Elisanti [20] who found that STEAM-based learning media were effective in improving critical thinking and scientific literacy at the elementary school level. This study extends the validity of that principle to higher education, demonstrating that this interdisciplinary approach is relevant across the entire educational spectrum. Second, the success of this intervention reaffirms the well-documented effectiveness of the PjBL and PBL models. A large body of literature indicates that PjBL is highly effective in fostering creativity, collaboration, and authentic problem-solving [8], [9], [10]. At the same time, PBL has been proven to excel in enhancing critical thinking, self-directed learning skills, and long-term knowledge retention [15], [18]. This study demonstrates that combining these two innovative learning models within a unified STEAM framework creates a particularly robust and holistic learning environment.

While aligning with these general trends, this study offers a unique contribution. Many previous studies, such as those conducted by other researchers [17], [21], have tended to focus on developing a single, specific medium or model (e.g., a mobile application or an e-module). In contrast, this study demonstrates how a cohesive curriculum embodied in comprehensive teaching materials that integrate various STEAM-based pedagogical strategies can be effectively designed and implemented. Furthermore, unlike some studies that report significant implementation challenges in STEAM, such as a lack of supporting materials or insufficient teacher readiness [10], the success of this intervention underscores a crucial point: the development of well-structured and rigorously expert-validated teaching materials is a key factor in bridging the gap between theory and practice and in overcoming implementation barriers.

Research Limitations and Future Directions

A critical reflection on the methodology employed is essential to maintain scientific objectivity and to provide a foundation for future research. This study has several limitations that must be acknowledged. First, concerning methodological limitations, the primary weakness is the use of a one-group pretest-posttest pre-experimental design with a relatively small sample size (N = 25). Without a control group, it isn't easy to definitively attribute the entire increase in HOTS scores solely to the instructional materials. Confounding factors, such as the natural maturation of students, testing effects (repeated exposure to the test), or the mere increase in motivation from participating in a study (the Hawthorne effect), cannot be entirely ruled out as alternative explanations.

Furthermore, the essay-based assessment of HOTS, while information-rich, introduces potential for subjectivity in scoring. The study does not report the use of an extensively validated scoring rubric or procedures to ensure inter-rater reliability, which may limit the objectivity of the outcome measures. Second, regarding the limitations of generalizability (external validity), the findings are inherently contextual. The research was conducted at a single institution (Unisla) with a specific population (students in the science education program). Therefore, generalizing these results to different student populations, academic programs, or types of universities requires considerable caution. The effectiveness of the instructional materials may be influenced by the unique characteristics of the students, instructors, and curricular context at the research site. These limitations, however, pave the way for several pertinent recommendations for future research:

1. Experimental Designs: Future research should employ a quasi-experimental or, ideally, a true experimental design with random assignment to treatment and control groups. Such a design would better isolate the intervention's effects and provide stronger causal evidence.

2. Larger and More Diverse Samples: Replication studies with larger, more heterogeneous samples—encompassing students from various institutions, backgrounds, and academic disciplines—are needed to test the generalizability of these findings.
3. Component Analysis: To address the fundamental question of how and why STEAM works, future research could design component analysis studies to investigate the underlying mechanisms. For example, by comparing a group receiving the STEAM-PjBL curriculum (with 'Arts') to a group receiving a STEM-PjBL curriculum (without 'Arts'), researchers could empirically measure the unique contribution of the arts component to creativity and other aspects of HOTS.
4. More Robust Measurement: Subsequent studies should use standardized and validated HOTS assessment instruments. Furthermore, implementing procedures to ensure scoring reliability, such as using two independent raters and calculating inter-rater reliability statistics (e.g., Cohen's Kappa), would significantly enhance the objectivity of the findings.
5. Longitudinal Studies: To understand the long-term impact, longitudinal studies could be conducted to track whether the observed gains in HOTS are sustained over time and whether these skills positively correlate with subsequent academic performance, in-field teaching practices, or professional success.

Implications

Despite acknowledged methodological limitations, this study provides promising preliminary evidence that meticulously designed instructional materials, integrating the interdisciplinary STEAM approach with active pedagogical models such as PjBL and PBL, can effectively enhance various dimensions of HOTS in pre-service science teachers. The main contribution of this study lies in demonstrating the development and implementation of a cohesive, validated curriculum as a practical solution to the challenge of applying STEAM in higher education. These findings have significant implications for educational practice. For educators and curriculum developers, this study highlights that transitioning from content-centred teaching to an authentic, interdisciplinary, and project-based approach is a robust strategy for equipping students with essential 21st-century skills, such as complex problem-solving, creativity, and critical thinking [2], [18], [19]. More specifically, the research highlights the importance of investing in the development of high-quality, comprehensive learning resources. These resources serve as a crucial bridge to ensure the successful and effective classroom implementation of innovative approaches, such as STEAM. Ultimately, by equipping pre-service teachers with HOTS through the very methods they will be expected to apply in the future, teacher education programs can create a sustainable cycle of pedagogical improvement. This not only enhances the quality of the pre-service teachers themselves but also has the potential for a broad positive impact on the quality of science education at the school level, thereby preparing future generations to face the challenges of an increasingly complex world.

CONCLUSION

This study confirms that instructional materials designed through the synergistic integration of the STEAM framework and an innovative learning model such as Project-Based Learning (PjBL) serve as an effective intervention to significantly enhance Higher-Order Thinking Skills (HOTS) among pre-service science teachers. The research objective to develop and evaluate valid and effective instructional materials was achieved, as evidenced by three key findings: (1) high expert validation scores (average of 88%), (2) a substantial improvement in student performance with an average N-Gain score in the 'High' category (0.78), and (3) highly positive student perceptions (average of 89.2%). The novelty of this research lies in presenting a comprehensive and thoroughly tested package of instructional materials. Unlike many other studies that might only test a single application or learning activity, this study provides a practical blueprint that demonstrates how the broad concept of STEAM can be tangibly implemented in the classroom through structured materials. This offers educators a concrete solution rather than merely a theoretical idea. Further analysis indicates that this intervention was particularly successful in fostering improvement in the domains of creative thinking (N-Gain = 0.85), critical thinking (N-Gain = 0.78), and analytical thinking (N-Gain = 0.69).

However, these findings should be interpreted in light of the study's limitations. The use of a one-group pre-experimental design without a control group limits the ability to draw definitive causal conclusions. Furthermore, the small sample size (N = 25) and its confinement to a single institution restrict the generalizability of the results. At the same time, the use of an essay-based instrument introduces potential subjectivity in scoring. Based on these findings and limitations, this study offers the following recommendations: (1) for practitioners, these instructional materials can serve as a validated template for designing interdisciplinary learning experiences; (2) for future researchers, it is advised to conduct studies using experimental or quasi-experimental designs, employ larger and more diverse samples, and adopt more objective HOTS assessment instruments to strengthen the validity of the findings.

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