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Article

Development of STEAM-Based Physics Learning Kits as Instructional Media to Improve High School Students' Critical Thinking Skills

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ABSTRACT

Critical thinking skills are essential competencies in 21st-century physics education, yet conventional instruction still tends to emphasize memorization and procedural learning. This study aimed to develop STEAM-based physics learning kits as instructional media to improve high school students' critical thinking skills. The study employed a Research and Development (R&D) approach using the ADDIE model consisting of analysis, design, development, implementation, and evaluation stages. The participants were 35 eleventh-grade students at SMA Negeri 1 Sidoarjo selected through purposive sampling. The developed learning kits integrated Science, Technology, Engineering, Arts, and Mathematics (STEAM) components with critical thinking indicators, including analysis, inference, evaluation, interpretation, and explanation. Validation conducted by an experienced physics teacher indicated that the developed learning kits were categorized as very valid with an average score of 4.57. The implementation results showed a significant improvement in students' critical thinking skills, reflected by the increase in average scores from 56.43 on the pretest to 82.17 on the posttest. The average N-gain score was 0.68, categorized as moderate improvement, while the paired sample t-test showed a statistically significant difference between pretest and posttest scores ($p < 0.05$). Students also responded positively toward the developed learning kits in terms of attractiveness, usability, and support for conceptual understanding and collaborative learning. The findings indicate that the developed STEAM-based physics learning kits effectively facilitate meaningful physics learning and support students' critical thinking development aligned with the demands of 21st-century education.

INTRODUCTION

The improvement of educational quality remains a central priority in preparing competitive human resources in the 21st century (Saepurokhman et al., 2025). Quality education functions as the foundation for developing human resources capable of adapting to rapid social and technological changes (Cong, 2025; Dwikoranto et al., 2025). Along with the rapid advancement of science and technology, educational systems are required to continuously transform to ensure that learning processes remain relevant to societal and industrial demands (Latifah et al., 2024). Consequently, 21st-century education increasingly emphasizes competencies such as communication, collaboration, creativity, and critical thinking as essential skills for future work and lifelong learning (Foster, 2023; Thornhill-Miller et al., 2023). Learning is therefore no longer limited to the transmission of knowledge but is directed toward the development of higher-order thinking skills through meaningful, student-centered, and technology-integrated learning environments (González-Pérez & Ramírez-Montoya, 2022; van Laar et al., 2022; Aires et al., 2025).

Among the competencies emphasized in 21st-century education, critical thinking is particularly important because it enables students to analyze information, evaluate evidence, and make logical decisions grounded inscientific reasoning (Puspawati et al, 2021; Mubarok et al., 2026). Critical thinking is not only an academic competence but also a fundamental cognitive process that supports reasoning, decision-making, and problem-solving in uncertain situations (Riva et al., 2023; Rothinam et al., 2025). It involves the ability to analyze information, evaluate evidence, make logical inferences, and construct well-reasoned arguments (Kayani & Tariq, 2023; Vieira et al., 2023). Accordingly, the development of critical thinking has become a major indicator of successful learning, particularly in science and physics education, where students are expected to actively construct knowledge through inquiry and analytical reasoning (Bazarbayeva & Aitbayeva, 2023; Ng et al., 2024). Previous studies have demonstrated that instructional models specifically designed to promote higher-order thinking significantly improve students' critical thinking performance and cognitive engagement (Kwangmuang et al., 2021; Fuad et al., 2019).

The importance of critical thinking becomes increasingly evident in physics education because students are required not only to understand theoretical concepts but also to interpret phenomena, analyze relationships, and apply principles in various contexts (Ma et al., 2023). Physics learning demands conceptual reasoning and analytical thinking since many phenomena are interconnected and represented through abstract mathematical models (Docktor & Mestre, 2019; Pospiech & Fischer, 2022). However, despite its recognized importance, the development of students' critical thinking skills in physics learning remains suboptimal. One major contributing factor is the persistence of conventional instructional practices that emphasize memorization and procedural problem-solving rather than inquiry and conceptual exploration (Musengimana et al., 2025). In such learning environments, students often function as passive recipients of information instead of active constructors of knowledge (Sekwena, 2023). As a result, learning tends to focus on surface-level understanding, while opportunities to develop deeper cognitive processes are limited. Several studies have reported that teacher-centered instruction restricts students' engagement in inquiry, reflection, and argumentation processes that are essential for critical thinking development (Fitriani et al., 2019).

This issue becomes more challenging because many physics concepts are inherently abstract and difficult to visualize. Topics such as energy transformation, fluid dynamics, and force interactions cannot always be directly observed, causing students to experience conceptual difficulties and misconceptions (Garg et al., 2025). These misconceptions often lead to fragmented understanding and limit students' ability to apply concepts in problem-solving situations (Soeharto et al., 2019). Research in physics education consistently identifies misconceptions and conceptual difficulties as major barriers to meaningful learning outcomes (Krijtenburg-Lewerissa et al., 2019; Mulhall et al., 2018). Therefore, innovative instructional approaches are needed to bridge the gap between abstract theories and observable phenomena while simultaneously facilitating the development of students' critical thinking skills.

To address these challenges, learning media have become increasingly important in creating meaningful and interactive learning experiences. Instructional media such as teaching aids, experimental tools, and physics kits provide opportunities for students to directly engage with concepts through observation, experimentation, and manipulation of variables (Girwidz et al., 2022;

Anselmo, 2024). Through these hands-on experiences, students are better able to connect abstract concepts with real-world phenomena, which supports deeper conceptual understanding and critical thinking development (Shanta, 2022). Previous studies have shown that interactive and technology-supported learning media improve students' motivation, engagement, and conceptual retention in science learning (Ibáñez & Delgado-Kloos, 2018; Cheng, 2021). In addition, virtual laboratories and simulation-based environments allow students to conduct exploratory learning activities that support inquiry and analytical thinking processes (Potkonjak et al., 2018).

In this context, the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach has emerged as a promising framework for designing innovative learning experiences (Wannapiroon & Pimdee, 2022; Papadopoulou, 2024). STEAM emphasizes interdisciplinary integration and encourages students to apply scientific concepts through creative and problem-solving activities (Perignat & Katz-Buonincontro, 2019). In physics education, STEAM-based learning kits enable students to explore concepts not only theoretically but also practically through structured experimental and engineering design activities (Rahmayanti & Rahardjo, 2024). This approach has been shown to enhance engagement, conceptual understanding, creativity, and active participation in learning (Herro et al., 2019; Ozkan & Umdu Topsakal, 2021). Furthermore, interdisciplinary STEAM projects positively influence students' motivation and scientific literacy by providing authentic learning experiences (Aguilera et al., 2021).

Although previous studies have demonstrated the positive impact of STEAM-based instructional media on learning outcomes, most studies primarily focus on conceptual mastery, engagement, or technological innovation rather than explicitly fostering critical thinking skills (Rosyida et al., 2025). Existing physics kits are generally designed as experimental tools that facilitate concept demonstration and procedural activities, but they rarely integrate structured cognitive processes into the learning design. Critical thinking indicators such as analysis, evaluation, inference, and explanation are often not explicitly embedded within student activities, resulting in learning experiences that are practical but not cognitively guided. Furthermore, many existing STEAM-based learning media are merely adaptations or modifications of conventional kits without systematic pedagogical structuring aimed at higher-order thinking development (Conradty & Bogner, 2020). This condition indicates a clear research gap regarding the development of pedagogically structured STEAM-based learning media specifically designed to facilitate critical thinking skills in physics learning.

To address this gap, the present study develops a STEAM-based physics learning kit specifically designed to integrate critical thinking indicators into every stage of learning activities. Unlike conventional physics kits that primarily function as experimental tools, the proposed STEAM-KIT combines hands-on experimentation, engineering design activities, problem-solving tasks, artistic visualization, and guided inquiry processes within a unified instructional framework. The developed product is not merely a modification of existing kits, but a pedagogically structured learning system consisting of experimental apparatus, student worksheets, inquiry-based activities, and critical thinking-oriented tasks. Each activity is systematically designed to train students' abilities in analyzing phenomena, evaluating evidence, constructing explanations, and drawing logical conclusions during physics learning activities. Therefore, the novelty of this study lies in the systematic integration of explicit critical thinking indicators into the design of a STEAM-based physics learning kit and its implementation in real classroom contexts. This study is expected to contribute both theoretically and practically to physics education by providing a pedagogically grounded, empirically tested, and practically applicable learning innovation aligned with the demands of 21st-century education.

METHODS

This study employed a Research and Development (R&D) approach aimed at developing and evaluating STEAM-based physics learning kits as instructional media to improve high school students' critical thinking skills. The development process adopted the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The ADDIE model was selected because it provides a systematic and structured framework for developing instructional products that are pedagogically relevant and empirically validated. In addition to the development process, this study also applied a pre-experimental method using a one-group pretest–posttest design to examine the effectiveness of the developed learning kits in improving students' critical thinking skills.

The overall research procedure followed the ADDIE development stages consisting of analysis, design, development, implementation, and evaluation. The detailed research procedure is presented in Figure 1.

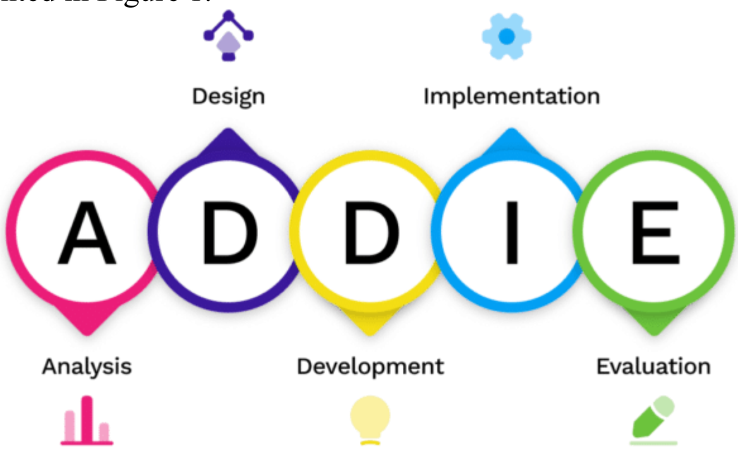

Figure 1. ADDIE Development Stages

The research was conducted at SMA Negeri 1 Sidoarjo during the 2025/2026 academic year. The participants consisted of one class of eleventh-grade students selected through purposive sampling techniques. The sample comprised 35 students who participated in all stages of the implementation process. The selection of participants was based on several considerations, including the availability of physics learning facilities, the implementation of the independent curriculum, and the school's readiness to support STEAM-oriented learning activities.

At the analysis stage, preliminary observations and interviews with physics teachers were conducted to identify problems encountered during physics learning, particularly those related to students' critical thinking skills and conceptual understanding. The analysis revealed that students tended to experience difficulties in understanding abstract physics concepts and rarely engaged in learning activities that encouraged analytical and evaluative thinking. Curriculum analysis was also conducted to ensure that the developed learning kits aligned with the intended learning outcomes and competencies in the physics curriculum.

Based on the results of the needs analysis, the design stage focused on developing STEAM-based physics learning kits that integrated Science, Technology, Engineering, Arts, and Mathematics (STEAM) components into structured learning activities. The developed kits consisted of lesson plans, student worksheets, experimental tools and materials, learning instructions, and assessment instruments. The learning activities were designed to explicitly incorporate critical thinking indicators, including analysis, inference, evaluation, explanation, and interpretation. Inquiry-based and problem-solving approaches were integrated into the activities to encourage students to actively construct knowledge through experimentation, discussion, and reflection.

During the development stage, the prototype of the STEAM-based physics learning kits was validated by an experienced physics teacher to ensure the appropriateness and feasibility of the developed instructional media before classroom implementation. The instruments validated in this study included lesson plans, student worksheets, critical thinking test items, observation sheets, and student response questionnaires. Validation was conducted using a five-point Likert scale ranging from 1 (very poor) to 5 (excellent).

The validation process assessed several aspects, including content suitability, language clarity, instructional feasibility, media presentation, and the integration of STEAM components and critical thinking indicators. The average validation score was interpreted using the following criteria in Table 1:

Table 1. Validation Criteria

Score	Criteria
1.00 – 1.80	Invalid
1.81 – 2.60	Less Valid
2.61 – 3.40	Moderately Valid
3.41 – 4.20	Valid
4.21 – 5.00	Very Valid

Suggestions and feedback obtained from the validator were used to revise and improve the developed learning kits prior to implementation.

Instrument reliability was analyzed using Cronbach's Alpha coefficient to determine the internal consistency of the instruments. A Cronbach's Alpha coefficient greater than 0.70 indicated that the instruments were reliable and suitable for research implementation. Reliability analysis and descriptive statistical calculations were conducted using Microsoft Excel.

The implementation stage involved the application of the validated STEAM-based physics learning kits in physics learning activities conducted in one class consisting of 35 students. The learning process was carried out over several meetings on physics topics related to motion and energy. During the learning activities, students participated in collaborative investigations, experimental activities, engineering design tasks, and reflective discussions designed to stimulate critical thinking processes. Students were encouraged to analyze problems, formulate hypotheses, interpret data, evaluate findings, and communicate their conclusions through interdisciplinary learning experiences.

The evaluation stage aimed to determine the effectiveness and practicality of the developed learning kits. Evaluation was conducted through critical thinking tests, classroom observations, student response questionnaires, and teacher feedback. The critical thinking skills test was administered before and after the implementation of the learning kits to measure students' improvement. The test consisted of essay and problem-solving questions developed based on critical thinking indicators. Observation sheets were used to evaluate the implementation of learning activities and student participation during the learning process, while questionnaires were distributed to obtain students' perceptions regarding the attractiveness, usability, and effectiveness of the developed instructional media.

The effectiveness of the STEAM-based physics learning kits was analyzed using normalized gain (N-gain) scores calculated using the following formula:

$$N - Gain = \frac{Posttest - Pretest}{Maximum\ Score - Pretest}$$

The N-gain results were categorized as follows:

- High : $g \geq 0.70$
- Moderate : $0.30 < g \leq 0.70$
- Low : $g \leq 0.30$

A paired sample t-test was also conducted to determine whether there was a statistically significant difference between students' pretest and posttest scores at a significance level of 0.05. Validation data, questionnaire results, reliability analysis, descriptive statistics, and N-gain calculations were analyzed using Microsoft Excel.

Prior to conducting the research, permission was obtained from the school administration and the physics teacher at SMA Negeri 1 Sidoarjo. All students participated voluntarily, and the collected data were used solely for research purposes while maintaining participant confidentiality.

RESULTS AND DISCUSSION

The development of the STEAM-based physics learning kits was conducted systematically using the ADDIE model consisting of analysis, design, development, implementation, and evaluation stages. The developed product included lesson plans, student worksheets, experimental tools, instructional guides, and critical thinking assessment instruments integrated into STEAM-oriented learning activities. The learning kits focused on physics topics related to motion and energy and were implemented in one class consisting of 35 eleventh-grade students at SMA Negeri 1 Sidoarjo.

Analysis Stage

The analysis stage was conducted through classroom observations and interviews with the physics teacher to identify problems encountered during physics learning. The findings indicated that students experienced difficulties in understanding abstract physics concepts and were rarely involved in learning activities that stimulated analytical and evaluative thinking processes. Learning activities were still dominated by teacher-centered instruction and procedural problem-solving approaches, causing students to become passive recipients of information. As a result, opportunities to develop critical thinking skills through inquiry, experimentation, and discussion were limited.

In addition, the analysis revealed that existing instructional media had not fully facilitated interdisciplinary and hands-on learning experiences. Most learning activities focused primarily on conceptual explanation without integrating problem-solving and engineering design activities that could encourage students to think critically. Therefore, the development of STEAM-based physics learning kits was considered necessary to support more meaningful, interactive, and student-centered learning processes aligned with the demands of 21st-century education.

Design Stage

Based on the results of the needs analysis, the design stage focused on developing learning activities that integrated Science, Technology, Engineering, Arts, and Mathematics components into physics learning. The developed STEAM-based learning kits consisted of lesson plans, student worksheets, experimental tools, learning instructions, and critical thinking assessment instruments. The learning activities were systematically designed to facilitate students' critical thinking skills through inquiry-based experiments, collaborative investigations, engineering design projects, and reflective discussions.

The integration of STEAM components was explicitly embedded within each learning activity. Science components were integrated through conceptual investigations and experimentation processes, while technology components involved the use of instructional media and simple experimental tools. Engineering components were represented through design-based problem-solving activities that encouraged students to construct and evaluate solutions. Arts components were integrated through visualization, creativity, and presentation activities, whereas mathematics components supported quantitative analysis and interpretation of experimental data.

In addition, the learning activities were designed to explicitly incorporate critical thinking indicators, including analysis, inference, evaluation, interpretation, and explanation. Students were encouraged not only to conduct experiments but also to analyze phenomena, interpret findings, evaluate evidence, and communicate conclusions logically during collaborative learning activities

Development Stage

During the development stage, the prototype of the STEAM-based physics learning kits was validated by an experienced physics teacher to ensure the feasibility and appropriateness of the developed instructional media before classroom implementation. The validation process assessed several aspects, including content suitability, language clarity, instructional feasibility, media presentation, and the integration of STEAM components and critical thinking indicators. Figure 2 presents the validation results of the developed learning kits.

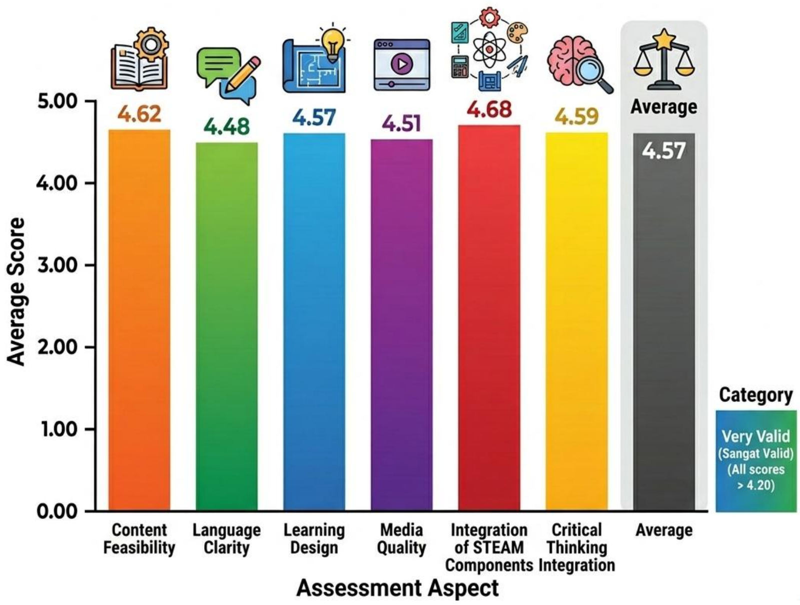

Figure 2. Validation Results of STEAM-Based Physics Learning Kits

The validation results indicate that the developed learning kits fulfilled the feasibility criteria and were categorized as very valid for classroom implementation. The highest validation score was obtained in the integration of STEAM components aspect, indicating that the developed learning activities successfully combined interdisciplinary learning experiences involving science, technology, engineering, arts, and mathematics within physics instruction. This aspect is important because interdisciplinary integration allows students to connect theoretical concepts with real-world applications through inquiry and problem-solving activities.

The high score obtained in the critical thinking integration aspect also demonstrates that the developed learning kits successfully embedded analytical and evaluative thinking processes into learning activities. Students were guided not only to conduct experiments but also to analyze data, evaluate findings, formulate explanations, and draw logical conclusions. This finding indicates that the developed learning kits functioned not only as experimental media but also as pedagogically structured instructional tools specifically designed to facilitate higher-order thinking development.

Several revisions were made based on the validator's suggestions before the implementation stage. Improvements included simplifying instructional language in the student worksheets, refining the sequence of inquiry activities, clarifying experimental procedures, and strengthening engineering design tasks within learning activities. In addition, several critical thinking questions were revised to better align with the indicators of analysis, inference, evaluation, interpretation, and explanation. These revisions improved the clarity, practicality, and pedagogical quality of the developed learning kits.

The findings of this study are consistent with previous studies reporting that STEAM-oriented instructional media promote meaningful learning experiences and improve higher-order thinking skills through interdisciplinary and inquiry-based learning environments.

However, unlike many previous STEAM-based learning products that mainly emphasized technological innovation and practical activities, the present study explicitly integrated critical thinking indicators into every stage of learning activities. Therefore, the developed learning kits contributed not only to experiential learning but also to the systematic development of students' critical thinking skills.

Implementation Stage

The implementation stage involved the application of the validated STEAM-based physics learning kits in physics learning activities conducted in one class consisting of 35 students. During the learning process, students participated in collaborative investigations, inquiry-based experiments, engineering design tasks, and reflective discussions designed to stimulate critical thinking processes. Students were actively involved in identifying problems, formulating hypotheses, analyzing experimental results, evaluating findings, and communicating conclusions through interdisciplinary learning experiences.

Students' critical thinking skills were measured using pretest and posttest assessments consisting of essay and problem-solving questions developed based on critical thinking indicators. The implementation results showed a significant improvement in students' critical thinking skills after participating in STEAM-based learning activities.

Table 2. Descriptive Statistics of Critical Thinking Skills Scores

Test	Mean Score	Minimum	Maximum
Pretest	56.43	42.0	71.0
Posttest	82.17	68.0	95.0

The data indicate that the average score increased from 56.43 on the pretest to 82.17 on the posttest, demonstrating substantial improvement after implementation of the STEAM-based physics learning kits. This improvement indicates that the developed instructional media effectively facilitated students' higher-order thinking development through interdisciplinary and inquiry-oriented learning activities.

The improvement in students' critical thinking skills was closely related to the characteristics of STEAM-based learning activities integrated within the developed learning kits. STEAM learning encourages students to actively engage in inquiry, problem-solving, engineering design, and collaborative investigations, all of which require analytical and evaluative thinking processes. During experiments and engineering activities, students were required to identify problems, formulate hypotheses, analyze data, evaluate alternative solutions, and communicate findings logically. These processes directly support the development of critical thinking skills, particularly analysis, inference, evaluation, and explanation abilities.

The integration of Science, Technology, Engineering, Arts, and Mathematics also created interdisciplinary learning experiences that encouraged students to connect theoretical concepts with real-world applications. Such contextual and hands-on learning activities support meaningful learning and stimulate higher-order thinking processes. This finding aligns with previous studies reporting that STEAM-oriented learning environments improve students' critical thinking, creativity, and problem-solving abilities because students are actively involved in reflective and inquiry-based learning processes.

Observation results also showed that students actively participated during learning activities. Students demonstrated enthusiasm during experiments, collaborative discussions, and engineering design tasks. Most students became more confident in expressing opinions, defending arguments, and communicating conclusions during classroom discussions. These findings indicate that the developed learning kits successfully created student-centered learning environments that encouraged active participation and reflective thinking processes.

Evaluation Stage

The evaluation stage aimed to determine the effectiveness and practicality of the developed learning kits through N-gain analysis, paired sample t-test analysis, classroom observations, and student response questionnaires.

Table 3. Distribution of Students' N-Gain Categories

N-Gain Category	Criteria	Number of Students	Percentage
High	g > 0.70	14	40.0%
Moderate	0.30 < g < 0.70	19	54.3%
Low	g < 0.30	2	5.7%
Total		35	100%

The results show that most students achieved moderate and high N-gain categories. A total of 40.0% of students achieved high improvement, while 54.3% achieved moderate improvement. Only 5.7% of students were categorized in the low improvement category. The average N-gain score obtained in this study was 0.68, categorized as moderate improvement, indicating that the developed learning kits effectively improved students' critical thinking skills. To determine the statistical significance of the improvement, a paired sample t-test was conducted.

Table 4. Paired Sample t-Test Results

Variable	t-value	Sig. (2-tailed)	Interpretation
Pretest-Posttest	14.27	0.000	Significant

The significance value obtained was lower than 0.05, indicating a statistically significant difference between students' pretest and posttest scores. Therefore, the implementation of the STEAM-based physics learning kits significantly improved students' critical thinking skills. Student responses toward the developed learning kits were also highly positive.

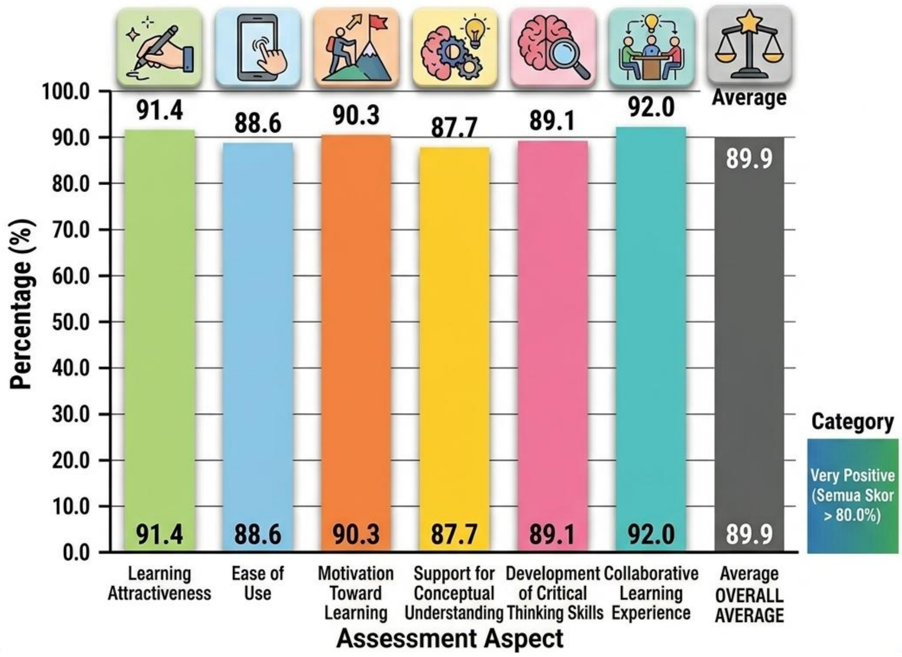

Figure 3. Student Responses Questionnaire Results

The questionnaire results indicate that students perceived the developed learning kits as engaging, interactive, and supportive of conceptual understanding and critical thinking development. The collaborative and inquiry-based learning activities encouraged students to become more actively involved in physics learning processes.

The findings demonstrate that the developed STEAM-based physics learning kits effectively improved students' critical thinking skills and supported meaningful learning experiences aligned with the demands of 21st-century education. The novelty of this study lies in the systematic integration of explicit critical thinking indicators within STEAM-oriented learning activities. Unlike many previous STEAM-based instructional products that mainly focused on practical experimentation and technological innovation, the developed learning kits intentionally embedded analytical, evaluative, and reflective thinking processes into every stage of learning activities. Therefore, the developed instructional media contributed not only to experiential learning but also to the pedagogical facilitation of higher-order thinking development in physics education.

The improvement in critical thinking skills was influenced by the structure of the learning activities, which explicitly integrated analysis, inference, evaluation, interpretation, and explanation into STEAM-oriented instruction. Through inquiry-based experiments, collaborative problem-solving, and engineering design tasks, students were encouraged to actively construct knowledge and evaluate information critically. These findings support previous studies emphasizing that STEAM learning environments promote higher-order thinking and meaningful learning experiences (Perignat & Katz-Buonincontro, 2019; Ozkan & Umdu Topsakal, 2021).

The hands-on experimental activities also played an important role in helping students visualize abstract physics concepts more concretely. This finding aligns with previous studies reporting that interactive learning media and experiment-based instruction improve conceptual understanding and student engagement in science learning (Ibáñez & Delgado-Kloos, 2018; Potkonjak et al., 2018). Furthermore, collaborative discussions and project-based activities created opportunities for students to communicate ideas, defend arguments, and evaluate alternative solutions, which are essential components of critical thinking development.

Another important finding is that the developed learning kits embedded critical thinking indicators systematically within learning activities. Unlike many previous STEAM-based instructional products that mainly emphasized technological innovation, this study focused on pedagogical structuring that intentionally facilitated cognitive skill development. As a result, students were not only engaged in practical activities but also guided to develop analytical and reflective thinking processes throughout the learning experience.

The positive student responses further indicate that the developed learning kits were practical and engaging for classroom implementation. Students perceived that STEAM-based learning activities increased motivation, improved conceptual understanding, and encouraged active participation in physics learning. Therefore, the developed learning kits can serve as an effective instructional innovation aligned with the demands of 21st-century education.

CONCLUSION

This study successfully developed STEAM-based physics learning kits as instructional media to improve high school students' critical thinking skills through the systematic integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) components within physics learning activities. The development process followed the ADDIE model consisting of analysis, design, development, implementation, and evaluation stages. The validation results indicated that the developed learning kits were categorized as very valid and feasible for classroom implementation. Revisions based on validator feedback improved the clarity of instructional language, inquiry activity sequences, experimental procedures, and the alignment of critical thinking indicators within learning activities. The developed learning kits also demonstrated strong integration of STEAM elements and critical thinking processes, particularly analysis, inference, evaluation, interpretation, and explanation skills.

The implementation results demonstrated that the STEAM-based physics learning kits effectively improved students' critical thinking skills, as indicated by the significant increase between pretest and posttest scores, moderate average N-gain results, and statistically significant paired sample t-test findings. The interdisciplinary, inquiry-based, and engineering-oriented learning activities encouraged students to actively participate in experimentation, collaborative investigations, problem-solving, and reflective discussions, which supported higher-order thinking development. In addition, students responded positively toward the developed learning kits in terms of attractiveness, usability, collaborative learning experiences, and support for conceptual understanding. Therefore, the developed STEAM-based physics learning kits can serve as an effective and innovative instructional medium for creating meaningful physics learning experiences aligned with the demands of 21st-century education. Future studies are recommended to involve larger samples, different physics topics, and more rigorous experimental designs to further examine the effectiveness of STEAM-based instructional media in various educational contexts

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REFERENCES

Aguilera, D., Ortiz-Revilla, J., & Greca, I. M. (2021). Review of interdisciplinary STEAM projects in science education. *Journal of Science Education and Technology, 30*, 45–65. https://doi.org/10.1007/s10956-020-09882-3

Aires, L., Amante, L., Fernández-Márquez, E., & Nunes, C. (2025). *Digital skills in distance university students: A psychometric analysis*.

Anselmo, C. T. (2024). Use of learning kits in physics education and its effectiveness: a meta-analysis. *Ignatian International Journal for Multidisciplinary Research, 2*(6), 307-323. https://doi.org/10.5281/zenodo.11474556

Bazarbayeva, S., & Aitbayeva, N. (2023). Improving critical thinking skills of master students through problem-based learning model. *Journal of Educational Sciences, 74*(1), 14-24. https://doi.org/10.26577/JES.2023.v74.i1.02

Cheng, K. H. (2021). A survey of native students' self-perceived learning effectiveness in AR-based educational environments. *Computers & Education, 166*, 104–134. https://doi.org/10.1016/j.compedu.2021.104134

Cong, D. H. (2025). Sustainable Development of High-Quality Human Resources. *Revista Gestão & Tecnologia, 25*(2), 287-315. https://doi.org/10.20397/2177-6652/2025.v25i2.3159

Conradty, C., & Bogner, F. X. (2020). STEAM teaching professional development works: Effects on students' creativity and motivation. *Smart Learning Environments, 7*(1). https://doi.org/10.1186/s40561-020-00132-9

Docktor, J. L., & Mestre, J. P. (2019). Synthesis of discipline-based education research in physics. *Physical Review Physics Education Research, 15*(2). https://doi.org/10.1103/PhysRevPhysEducRes.15.020119

Dwikoranto, Lintangesukmanjaya, R. T., Astutik, W., Mubarok, W. K., Putra, D. A., Setiani, R., & Bergsma, L. N. (2025). Program evaluation in improving high school physics learning outcomes through an experimental analysis approach. *Journal of Physics: Conference Series, 3132*(1), 012013. https://doi.org/10.1088/1742-6596/3132/1/012013

Foster, N. (2023). 21st Century competencies: Challenges in education and assessment. *Innovating assessments to measure and support complex skills*, 30-44.

Fuad, N. M., Zubaidah, S., Mahanal, S., & Suarsini, E. (2019). Improving junior high schools' critical thinking skills based on test three different models of learning. *International Journal of Instruction, 10*(1), 101–116. https://doi.org/10.12973/iji.2017.1017a

Garg, A., Akkinepally, B., Sarkar, J., & Pattanayek, S. K. (2025). Emerging perspectives in non-Newtonian fluid dynamics: Research gaps, evolving methods, and conceptual limitations. *Physics of Fluids, 37*(7), 071401. https://doi.org/10.1063/5.0278915

Girwidz, R., Theyßen, H., & Widenhorn, R. (2022). Experiments in physics teaching. *In Physics education* (pp. 269-296). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-87391-2_10

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of Education 4.0 in 21st Century Skills Frameworks: Systematic Review. *Sustainability, 14*(3), 1493. https://doi.org/10.3390/su14031493

Herro, D., Quigley, C., Andrews, J., & Delacruz, G. (2019). Co-measuring creativity and critical thinking in STEAM activities. *Journal of Science Education and Technology, 26*(5), 410–426. https://doi.org/10.1007/s10956-017-9679-0

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education, 123*, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Kayani, S., & Tariq, A. (2023). Role of discussion method in developing logical reasoning in students at university level. *International Journal of Emerging Trends in Education, 1*(3), 16-29. https://doi.org/10.5281/ijete.v1i3.33

Krijtenburg-Lewerissa, K., Pol, H. J., Brinkman, A., & van Joolingen, W. R. (2019). Insights into teaching quantum mechanics in secondary and lower undergraduate education. *Physical Review Physics Education Research, 13*(1). https://doi.org/10.1103/PhysRevPhysEducRes.13.010109

Kwangmuang, P., Jarutkamolpong, S., Sangboonraung, W., & Daungtod, S. (2021). The development of learning innovation to enhance higher order thinking skills for students in Thailand junior high schools. *Heliyon, 7*(6), e07309. https://doi.org/10.1016/j.heliyon.2021.e07309

Latifah, S., Wiliyanti, V., & Sari, I. P. (2024). Design And Implementation Of E-Lkpd Using The Lok-R Model For Electromagnetic Wave Material In Senior High School. *INSECTA: Integrative Science Education and Teaching Activity Journal,* 5(2), 234–248. https://doi.org/10.21154/insecta.v5i2.9866

Lintangesukmanjaya, R. T., Mahendra, A., Anugrah, S., Prahani, B. K., Dwikoranto, D., Satriawan, M., & Rizki, I. A. (2025). A EFA Analysis of Digital Technology Teaching Materials in Improving Students' Critical Thinking in Physics Learning. *JPPS (Jurnal Penelitian Pendidikan Sains),* 23–38. https://doi.org/10.26740/jpps.v14n1.p23-38

Ma, X., Zhang, Y., & Luo, X. (2023). Students' and teachers' critical thinking in science education: are they related to each other and with physics achievement?. *Research in Science & Technological Education, 41*(2), 734-758. https://doi.org/10.1080/02635143.2021.1944078

Mubarok, W. K., Anugrah, S., & Citra, N. F. (2026). Mapping Augmented Reality in Physics Education for Enhancing Students' Critical Thinking Skills: A Bibliometric Analysis (2015–2026). *Studies in Bibliometrics of Education and Technology*, *1*(2), 1-13. Retrieved from https://www.scie-journal.net/index.php/SiBET/article/view/8

Mulhall, P., McKittrick, B., & Gunstone, R. (2018). A perspective on the resolution of misconceptions in physics. *Research in Science Education, 48*(6), 1243–1260. https://doi.org/10.1007/s11165-016-9606-1

Musengimana, T., Yadav, L. L., Uwamahoro, J., & Nizeyimana, G. (2025). Instructional strategies for enhancing students' problem-solving skills in physics: a systematic review. *Discover Education, 4*(1), 380. https://doi.org/10.1007/s44217-025-00733-x

Ng, D. T. K., Tan, C. W., & Leung, J. K. L. (2024). Empowering student self-regulated learning and science education through ChatGPT: A pioneering pilot study. *British Journal of Educational Technology, 55*(4), 1328-1353. https://doi.org/10.1111/bjet.13454

Ozkan, G., & Umdu Topsakal, U. (2021). Investigating the effectiveness of STEAM education on students' conceptual understanding and scientific creativity. *Education and Information Technologies, 26*, 4573–4596. https://doi.org/10.1007/s10639-021-10448-z

Papadopoulou, E. A. (2024). Advancements in STEAM education for 21st century learners. *International Journal of Education, 16*(4), 39-70. https://doi.org/10.5296/ije.v16i4.22270

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity, 31*, 31–43. https://doi.org/10.1016/j.tsc.2018.10.002

Pospiech, G., & Fischer, H. E. (2022). Physical–mathematical modelling and its role in learning physics. In *Physics education* (pp. 201-229). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-87391-2_8

Potkonjak, V., Gardner, M., Callaghan, V., et al. (2018). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education, 95*, 309–327. https://doi.org/10.1016/j.compedu.2016.02.002

Puspawati, N. W. N., Suwastini, N. K. A., Hutapea, J. V., Dantes, G. R., & Adnyani, N. L. P. S. (2021, March). Consumption and production of short film: toward the conceptualization of multimodal language learning for developing 6cs skills in the digital age. In *Journal of Physics: Conference Series* (Vol. 1810, No. 1, p. 012054). IOP Publishing. https://doi.org/10.1088/1742-6596/1810/1/012054

Rahmayanti, L., & Rahardjo, S. B. (2024). Analyzing Project Outcomes and Students' Responses of Renewable Energy STEAM Kit. *Jurnal Penelitian Pendidikan IPA, 10*(9), 7103-7112. https://doi.org/10.29303/jppipa.v10i9.8485

Rivas, S. F., Saiz, C., & Almeida, L. S. (2023). The role of critical thinking in predicting and improving academic performance. *Sustainability, 15*(2), 1527. https://doi.org/10.3390/su15021527

Rosyida, K. M. I., Prahani, B. K., & Kurtuluş, M. A. (2025). Analysis of the Role of STEAM Education in improving critical thinking skills for sustainable development. *Journal of Current Studies in SDGs, 1*(1), 20-32. https://doi.org/10.63230/jocsis.1.1.9

Rothinam, N., Vengrasalam, R., Naidu, S., Nachiappan, S., & Jabamoney, S. (2025). Systematic literature review on critical thinking in higher education. *Edelweiss Applied Science and Technology, 9*(5), 2046-2063

Saepurokhman, A., Pugu, M. R., & Meisarah, F. (2025). Strategies for Transforming 21st Century Education to Realise Competitive Human Resources Towards the Golden Generation: A Literature Review. *Berajah Journal, 5*(3), 305-314. https://doi.org/10.47353/bj.v5i3.611

Sekwena, G. L. (2023). Active learning pedagogy for enriching economics students' higher order thinking skills. *International Journal of Learning, Teaching and Educational Research, 22*(3), 241-255. https://doi.org/10.26803/ijlter.22.3.15

Shanta, S. (2022). Assessment of real-world problem-solving and critical thinking skills in a technology education classroom. In *Applications of research in technology education: Helping teachers develop research-informed practice* (pp. 149-163). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-16-7885-1_10

Soeharto, Csapó, B., Sarimanah, E., Dewi, F. I., & Sabri, T. (2019). A review of students' common misconceptions in science and their diagnostic assessment tools. *Jurnal Pendidikan IPA Indonesia, 8*(2), 247–266. https://doi.org/10.15294/jpii.v8i2.18649

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J.-M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence, 11*(3), 54. https://doi.org/10.3390/jintelligence11030054

van Laar, E., van Deursen, A. J., & van Dijk, J. A. (2022). Developing policy aimed at 21st-century digital skills for the creative industries: an interview study with founders and managing directors. *Journal of Education and Work, 35*(2), 195-209. https://doi.org/10.1080/13639080.2022.2036710

Vieira, R. M., Tenreiro-Vieira, C. C., Bem-Haja, P., & Lucas, M. (2023). STEM teachers' digital competence: Different subjects, different proficiencies. *Education Sciences, 13*(11), 1133. https://doi.org/10.3390/educsci13111133

Wannapiroon, N., & Pimdee, P. (2022). Thai undergraduate science, technology, engineering, arts, and math (STEAM) creative thinking and innovation skill development: a conceptual model using a digital virtual classroom learning environment. *Education and Information Technologies, 27*(4), 5689-5716. https://doi.org/10.1007/s10639-021-10849-w

Yakman, G. (2019). STEAM education: an overview of creating a model of integrative education. *Pupil: International Journal of Teaching, Education and Learning, 3*(1), 1–18. https://doi.org/10.20319/pijtel.2019.31.118