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Development of E-Student Worksheet Based on STEM Approach with PBL Model to Facilitate Critical Thinking Skills on Momentum and Impulse Material

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ABSTRACT

This research is motivated by the low critical thinking skills of students in physics learning and the unavailability of digital teaching materials capable of supporting the implementation of the Independent Curriculum. This study aims to develop and analyze the validity of Electronic Student Worksheets based on the Science, Technology, Engineering, and Mathematics (STEM) approach with the Problem Based Learning (PBL) model on momentum and impulse material to facilitate critical thinking skills of high school students. This study uses the Research and Development (R&D) method with the Four-D (4D) model limited to the define, design, and develop stages. Product validity was assessed by three expert validators using validation instruments analyzed with the Aiken's V index. The results showed that the developed E-Student Worksheet obtained an average validity value of 0.87 with a very valid category. All assessment aspects, namely material substance, visual communication display, E-Student Worksheet components, software utilization, STEM approach, PBL model, and critical thinking skills, were in the very valid category. Based on these results, the STEM-based E-Student Worksheet with the PBL model is declared suitable for use as a digital teaching material to support physics learning on momentum and impulse materials and has the potential to facilitate the development of students' critical thinking skills.

INTRODUCTION

The development of science and technology in the Industrial Revolution 4.0 era has brought significant changes to various aspects of life, including education (Putri, Anaperta, & Yanti, 2024). Advances in digital technology have transformed the way humans obtain information, communicate, and learn, thus encouraging the birth of more flexible, interactive, and student-centered learning innovations (Kalsum, Siahaan, & Program Studi Magister Pendidikan Fisika, 2023). The integration of technology into the learning process is an important strategy to support the implementation of the Independent Curriculum, which emphasizes student-centered learning, strengthening 21st-century competencies, and developing the Pancasila Student Profile (Fianingrum et al., 2023; Andi Sadriani et al., 2023). Learning in the digital era no longer only utilizes technology as a medium for conveying information, but also as a means to create collaborative, contextual, and problem-solving-oriented learning experiences (Muhaimin, 2021; Fricticarani et al., 2023). Therefore, teachers are required to be able to develop digital teaching materials that not only facilitate concept mastery but also develop students' higher-order thinking skills. The use of technology in digital learning offers significant opportunities to improve the quality of education through the use of various interactive media, such as digital simulations, online learning platforms, instructional videos, and problem-based applications (Novitra et al., 2024). This technology enables students to more actively explore concepts, develop higher-order thinking skills, and construct knowledge independently. This aligns with the implementation of the Independent Curriculum, which provides students with the freedom to explore concepts in greater depth, enabling optimal development of 21st-century competencies (Ossy et al., 2024).

One of the 21st-century competencies that is a primary focus in physics learning is critical thinking skills (Atika & Mufit, 2024). According to Facione (2015), critical thinking is the ability to interpret information, analyze relationships between concepts, evaluate evidence, draw logical conclusions, and reflect on the thought process when solving a problem. In physics learning, this skill is crucial because it helps students understand concepts deeply, connect theory to everyday phenomena, and systematically solve various scientific problems. Recent research also shows that critical thinking skills contribute significantly to improved learning outcomes, problem-solving abilities, and student readiness to face 21st-century challenges (Utami & Emiliannur, 2025).

However, empirical conditions at SMAN 1 Banuhampu indicate that students' critical thinking skills remain very low. Observations indicate that the learning process is still dominated by a teacher-centered approach, resulting in students tending to be passive during the learning process. Based on the results of a pre-test of 32 11th-grade students, the average critical thinking skill score was 41.48%, with all critical thinking indicators according to Facione—interpretation, analysis, explanation, inference, evaluation, and self-regulation—falling in the low to very low categories. This situation is reinforced by teacher interviews and student questionnaires, which indicate that physics is still considered a difficult subject, learning is less engaging, the use of teaching materials is still limited to printed textbooks and PowerPoint presentations, and the lack of interactive digital teaching materials capable of facilitating active student engagement in the learning process.

One effort that can be made to overcome this problem is through the development of Electronic Student Worksheets. E-Student Worksheets is a digital teaching material that allows for interactive presentation of material through the integration of images, videos, animations, simulations, and technology-based learning activities (Virijai et al., 2022; Oktarina et al., 2023). The use of E-Student Worksheets provides opportunities for students to explore concepts independently, obtain direct feedback, and increase motivation, independence, and engagement during the learning process. Therefore, E-Student Worksheets is considered more effective than conventional worksheets in supporting the development of critical thinking skills (Virijai et al., 2022).

For E-Student Worksheets to optimally facilitate critical thinking skills, the integration of appropriate learning approaches is necessary. One relevant approach is Science, Technology, Engineering, and Mathematics (STEM), which integrates concepts of science, technology, engineering, and mathematics through contextual problem-solving. STEM-based learning encourages students to develop scientific thinking, creativity, communication, collaboration, and decision-making skills based on scientific evidence (Rahmana et al., 2022). Furthermore, the STEM approach aligns with the characteristics of the Independent Curriculum, which emphasizes contextual, collaborative, and student-centered learning.

The implementation of the STEM approach will be more optimal when combined with Problem-Based Learning (PBL). The PBL model is a student-centered learning model that begins learning by presenting real-life problems that must be solved through a process of scientific inquiry (Dariah et al., 2024; Enjellina et al., 2024). In its application, students are given the opportunity to identify problems, gather information, analyze various alternative solutions, conduct investigations, test the results of problem-solving, and communicate their findings (Maulidia et al., 2020; Septiani et al., 2020). Thus, the implementation of PBL not only improves mastery of physics concepts but also develops students' critical thinking, problem-solving, and collaboration skills (Septiani et al., 2020).

Various previous studies have shown that the development of STEM-based and PBL-based E-Student Worksheets has a positive impact on improving students' learning outcomes and critical thinking skills. Burnama et al. (2024) reported that Problem-Based Learning-based E-Student Worksheets can improve students' learning activities and analytical skills. Rahmana et al. (2022) demonstrated that the STEM approach can improve students' understanding of physics concepts and critical thinking skills. Recent research also shows that the use of STEM-based E-Student Worksheets developed through digital platforms can increase student engagement and support the development of critical thinking skills (Siswanto et al., 2025; Isra et al., 2025). However, most of this research focuses on material other than momentum and impulse, does not integrate the STEM approach and PBL model simultaneously, or has not been developed in accordance with the implementation of the Independent Curriculum at the high school level.

Based on these gaps, this study offers a novelty in the form of developing an E-Student Worksheets based on a STEM approach that is systematically integrated with the Problem Based Learning model on momentum and impulse materials using the Liveworksheet platform. The developed product is designed to facilitate all indicators of critical thinking skills according to Facione through contextual, interactive, collaborative, and problem-solving-based learning activities. Therefore, this study is expected to not only produce valid and practical digital teaching materials, but also contribute to the development of technology-based physics learning innovations that can improve students' critical thinking skills and become a reference for teachers in developing digital learning tools for other physics materials.

METHODS

This research is an R&D (Research and Development) study using the 4D model (Thiagarajan, 1974). The research stages are limited to three stages: definition, design, and development. The dissemination stage was not implemented due to time constraints. This development research aims to produce a valid, STEM-based electronic student worksheet using the PBL model on momentum and impulse to facilitate critical thinking skills in high school (SMA/MA) students.

This research begins with the definition stage, which is used to identify and formulate learning needs. Next, the research enters the design stage, which aims to design a physics electronic student worksheet for use in the learning process. At this stage, learning media are planned to best suit the conditions and characteristics of the students. The next stage is the development stage, which includes providing input and testing by experts. Expert validation is conducted to determine the feasibility of the created electronic student worksheet and to obtain advice from the experts.

This research was conducted at SMAN 1 Banuhampu and the Physics Department of Padang State University (UNP). This research was conducted in the odd semester of the 2026/2027 academic year. The subjects in this developmental research were three Physics lecturers from the Faculty of Mathematics and Natural Sciences, UNP, who acted as validators to test the validity of the developed E-Student Worksheets. The object of this developmental research was a STEM-based E-Student Worksheets with a PBL model on momentum and impulse to facilitate critical thinking skills in high school/Islamic high school students.

The data used in this study were primary data obtained directly from the research subjects. The data obtained from the validators were in the form of a validity test questionnaire for the STEM-based E-Student Worksheets with a PBL model on momentum and impulse to facilitate critical thinking skills in high school/Islamic high school students. Validity values were obtained by analyzing the questionnaires administered and completed by the validators. The validity assessment comprised several aspects, including material substance, visual communication displays, E-Student Worksheets components, software utilization, and the application of the STEM approach with a PBL model to support high school/Islamic high school students' critical thinking skills in the E-Student Worksheets.

Data obtained from the validity process were analyzed using the Aiken validity index to determine the suitability and validity of the E-Student Worksheets. Validity analysis used a Likert scale of 1 to 5 and was then processed using the Aiken formula to obtain the validity coefficient (Aiken, 1985). The Aiken V formula is as follows:

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

The description of the Aiken validity index formula includes the V value which indicates the validity index of an instrument, s which is obtained from the difference between the score given by the validator (r) and the lowest score on the assessment scale (l_0), so it is formulated as $s = r - lo$. The symbol l_0 represents the lowest score on the validation scale, which is 1, while c represents the highest score on the validation scale, which is 5. Furthermore, r states the score given by each validator to each assessment item, while n indicates the number of validators involved in the validation process. The s values from all validators are then added up to obtain the Aiken validity index value (V), which is used as a basis for determining the level of validity of the product being developed.

The final calculation results determine whether the E-Student Worksheets meets the established validity criteria. The validity criteria used can be seen in Table 1 below.

Table 1. Product Validity Criteria

Value	Criteria
≤ 0.4	Less Valid

0.4 ≤ V ≤ 0.8	Valid
0.8 ≤ V ≤ 1	Very Valid

(Retnawati, 2016)

RESULTS AND DISCUSSION

Results

The purpose of this development research is to develop and produce a STEM-based E-Student Worksheets with a valid PBM model to facilitate students' critical thinking skills on momentum and impulse materials. The creation of this E-Student Worksheets aims to provide interactive digital teaching materials that are in accordance with the needs of technology-based learning. The results obtained start from several stages to produce a valid E-Student Worksheets.

Define Stage

End Start Analysis

At this stage, the researchers conducted observations, interviews with teachers, and distributed questionnaires to students at SMAN 1 Banuhampu. Based on the observations, students' critical thinking skills in physics learning were found to be relatively low. During the learning process, students tended to be passive, and learning was predominantly teacher-centered. Table 2 presents the students' physics learning achievement data that support these findings.

Table 2. Students' Critical Thinking Skills Based on Facione's Indicators

Indicator	Score (%)	Category
Interpretation	40.416 %	Very Low
Analysis	33.906 %	Very Low
Explanation	31.875 %	Very Low
Inference	43.125 %	Very Low
Evaluation	45.625 %	Low
Self-Regulation	53.958 %	Low
Average	**41.484 %**	**Very Low**

At the define stage, observations, critical thinking tests, teacher interviews, and student questionnaires were conducted at SMAN 1 Banuhampu to identify the problems encountered in physics learning. The results of the observations revealed that students' critical thinking skills were still categorized as very low. During the learning process, students tended to be passive, learning activities were predominantly teacher-centered, and only a few students actively responded to the teacher's questions. In addition, many students were not fully engaged in the lesson, as indicated by behaviors such as talking to classmates, using mobile phones, or sleeping during class. The results of the critical thinking test, presented in Table 2, showed an average score of 41.484%, which falls into the very low category. Among the six indicators of critical thinking proposed by Facione (2015), the lowest achievement was found in the explanation indicator (31.875%), followed by analysis (33.906%), interpretation (40.416%), and inference (43.125%), all of which were categorized as very low. Meanwhile, the evaluation (45.625%) and self-regulation (53.958%) indicators were classified as low. These findings indicate that students still experience difficulties in interpreting information, analyzing problems, explaining scientific concepts, drawing conclusions, and evaluating solutions when solving momentum and impulse problems.

The interview results further revealed that many students perceived physics as a difficult subject because it involves numerous mathematical calculations and formulas. Teachers also reported that students' scientific literacy was relatively low, as many students tended to search directly for answers on the internet rather than attempting to solve problems independently. Furthermore, the limited use of innovative teaching materials and the suboptimal implementation of student-centered learning models were identified as factors contributing to students' low critical thinking skills. The questionnaire results supported these findings, indicating that students experienced difficulties in understanding momentum and impulse concepts because the learning process relied mainly on printed textbooks and PowerPoint presentations. Most students expressed a preference for more active learning supported by interactive digital teaching materials. Therefore, the development of a STEM-based E-Student Worksheet integrated with the Problem-Based Learning model is considered necessary to provide a more engaging learning experience and to facilitate the improvement of students' critical thinking skills.

Learner Analysis

The analysis of students aims to identify the characteristics of students at SMAN 1 Banuhampu related to their ability to create E-Student Worksheets based on the STEM approach with the PBL model on the topic of momentum and impulse to facilitate students' critical thinking skills. The results of the questionnaire show that students tend to have various learning styles, such as auditory, visual, audiovisual, and kinesthetic. Students want active physics learning and use learning media because they want a fun learning experience.

Table 3. Learning Styles Are Considered to Function for Understanding Learning

No.	Aspects	Percentage (%)
1.	Audio	25 %
2.	Visual	22 %
3.	Audiovisual	62.5 %
4.	Kinesthetic	37.5 %
5.	Other answer	6.25 %

These findings suggest that students tend to understand physics concepts more effectively when learning activities combine visual and auditory information with opportunities for active participation. The diversity of learning styles also indicates that a single instructional approach may not adequately accommodate all students' learning needs. Therefore, the developed E-Student Worksheet was designed by integrating interactive multimedia elements and STEM-based problem-solving activities within the PBL model to create a more engaging learning environment and to facilitate the development of students' critical thinking skills on the topic of momentum and impulse.

Task Analysis

Task analysis was conducted by analyzing the teacher's teaching module and the sequence of learning tasks that students are required to complete on the topic of momentum and impulse. This analysis aimed to identify the competencies that students should master and to determine the learning tasks that would serve as the basis for developing the STEM-based Electronic Student Worksheet integrated with the Problem-Based Learning (PBL) model. The analysis was carried out by reviewing the Learning Outcomes (CP), learning objectives, learning activities, and assessment components contained in the teacher's teaching module. The results of the task analysis are presented in Table 4.

Table 4. Learning Outcome Elements

Learning Task	Results of Task Analysis	Implications for E-Student Worksheet Development
Identifying the variables affecting momentum.	Students are expected to identify the relationship between mass, velocity, and momentum.	Interactive concept exploration activities were designed to strengthen students' conceptual understanding.
Analyzing the relationship between momentum and impulse.	Students are required to explain the mathematical and conceptual relationship between momentum and impulse.	STEM-based learning activities were developed to encourage analytical thinking through contextual problems.
Applying the law of conservation of momentum.	Students solve collision problems by applying the law of conservation of momentum.	Problem-Based Learning activities were integrated using real-life collision cases.
Analyzing different types of collisions	Students distinguish elastic, partially elastic, and perfectly inelastic collisions and relate them to everyday phenomena.	Contextual examples, simulations, and inquiry activities were incorporated into the E-Student Worksheet.
Applying the coefficient of restitution.	Students calculate and interpret the coefficient of restitution through experimental activities.	Experimental investigations and data analysis tasks were included to develop scientific reasoning and critical thinking skills.

The results of the task analysis presented in Table 4 indicate that the learning tasks are organized progressively, beginning with the identification of fundamental concepts and continuing to the application of physics principles in authentic problem-solving situations. The analysis of the teacher's teaching module shows that students are expected to master conceptual understanding, analytical thinking, experimental investigation, and the application of physics concepts to everyday phenomena. These learning tasks require higher-order cognitive processes, particularly analysis, application, and evaluation, which are closely associated with critical thinking skills. However, the existing teaching module mainly provides conceptual explanations and classroom activities without integrating STEM learning experiences and the systematic phases of the Problem-Based Learning model. Therefore, the developed Electronic Student Worksheet was designed to complement the teacher's teaching module by incorporating contextual STEM activities, inquiry-based investigations, and structured problem-solving tasks that facilitate the development of students' critical thinking skills on the topic of momentum and impulse.

Learning Material Analysis

Material analysis was conducted to identify the material to be presented in the developed student worksheets. The first step in this analysis was to review material deemed difficult for students to understand. The results of this analysis can be seen in Table 5.

Table 5. Materials Considered Difficult to Understand by Learners

No.	Aspects	Percentage (%)
1.	Momentum	25 %
2.	Impulse	44 %
3.	Impulse-momentum relationship	62.5 %
4.	Law of conservation of momentum	53 %
5.	Collision	47 %

The analysis results in Table 5 show that the material on the relationship between impulse and momentum is the most difficult material for students to understand with a percentage of 62.5%, followed by the law of conservation of momentum at 53%, collisions at 47%, impulse at 44%, and momentum at 25%. The high percentage of difficulties in the material on the relationship between impulse and momentum and the law of conservation of momentum indicates that students still have difficulty in connecting physics concepts with their application in problem solving. This condition indicates the need for teaching materials that are able to present material in a more contextual, systematic, and interactive manner so that students can build a deeper understanding of concepts. Therefore, the development of E-Student Worksheets based on the STEM approach with the Problem Based Learning model is focused on the material on momentum and impulse as an effort to help students understand concepts through investigative activities, problem solving, and application of concepts in real situations so as to facilitate critical thinking skills.

Learning Objectives Analysis

Learning objective analysis was conducted through a context analysis of the teacher's teaching module used in physics learning at SMAN 1 Banuhampu. This analysis aimed to identify the suitability of the learning outcomes, learning objectives, learning activities, teaching materials, and assessment strategies implemented by the teacher with the needs of the developed STEM-based Electronic Student Worksheet integrated with the Problem-Based Learning (PBL) model. The results of this analysis were used as the basis for determining the learning objectives, learning activities, and assessment components incorporated into the developed E-Student Worksheet. The findings of the context analysis of the teacher's teaching module are presented in Table 6.

Table 6. Context Analysis of the Teacher's Teaching Module

Aspects Analyzed	Results of Teacher Learning Module Analysis	Implications for E-Student Worksheet Development
Learning Outcomes	Refers to Phase F of the Independent Curriculum.	The E-Student Worksheet is structured to align with the applicable CP.
Learning Objectives	Focuses on understanding the concepts of momentum, impulse, and collision.	Objectives are expanded to facilitate critical thinking skills.
Learning Activities	Uses apperception, discussion, reflection, and teacher explanation.	Activities are developed into problem-based

		learning through PBL syntax.
Learning Approach	Does not explicitly integrate STEM.	The E-Student Worksheet integrates elements of Science, Technology, Engineering, and Mathematics.
Teaching Materials	Uses conventional teaching modules and learning resources.	Digital teaching materials were developed in the form of interactive E-Student Worksheet.
Assessment	Initial and reflective assessments are provided, but they do not specifically measure critical thinking indicators.	Assessments in E-Student Worksheet are structured based on Facione's critical thinking indicators.

The analysis showed that the teaching module has been developed in accordance with the Learning Outcomes (CP) of the Merdeka Curriculum for Phase F and includes contextual learning activities, initial assessment, classroom discussions, and reflection activities. However, the module primarily emphasizes conceptual understanding and classroom discussions, while the integration of the STEM approach and the Problem-Based Learning (PBL) model has not been explicitly implemented in a systematic manner. In addition, although the module encourages students to develop critical thinking, the learning activities and assessments have not been specifically designed to facilitate critical thinking skills based on Facione's indicators. The analysis also indicates that the teaching materials are still limited to conventional learning resources and have not been supported by interactive digital worksheets. Therefore, the developed STEM-based E-Student Worksheet integrated with the PBL model was designed to complement the existing teaching module by providing structured STEM learning activities, contextual problem-solving tasks, and assessment activities that facilitate the development of students' critical thinking skills in learning the concepts of momentum and impulse.

Results of Development Stage (Disseminate)

The validation of the STEM-based E-Student Worksheets product with a PBL model on momentum and impulse, designed to facilitate students' critical thinking skills, has been validated by three validators. The three validators are lecturers from the Physics Department, Faculty of Mathematics and Natural Sciences, Padang State University. The validators assessed the E-Student Worksheets created by the author by completing a validation questionnaire. Aspects assessed in the validity test included the material's substance, visual communication display, E-Student Worksheets components, software utilization, and the application of the STEM approach with a PBL model to facilitate high school/Islamic high school students' critical thinking skills in the E-Student Worksheets.

The first aspect of the validity instrument used in the development of ICT-based teaching materials according to (Direktorat Pembinaan SMA, 2010) is the substance of the material. This aspect includes four assessment indicators: 1) accuracy, 2) material coverage, 3) relevance, and 4) readability. The results can be seen in the graph shown in Figure 1.

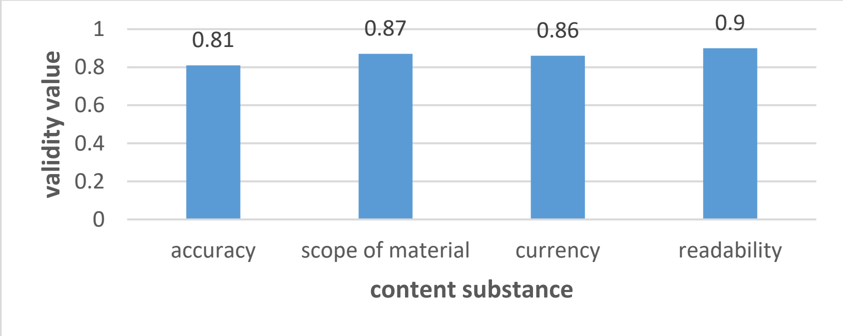

Figure 1. Aspects of Material Substance

Based on the results obtained in Figure 1 regarding the material substance aspect, the validation results for this aspect ranged from 0.81 to 0.9. The first indicator, the accuracy of the material in the E-Student Worksheets, obtained a score of 0.81, which can be categorized as very valid. The second indicator, the coverage of the material in the E-Student Worksheets, scored 0.87, which can also be categorized as very valid. The third indicator, the presentation of the material in the E-Student Worksheets, scored 0.86, which can be categorized as very valid. Finally, the readability indicator scored 0.9, which can be categorized as very valid. Thus, the overall average validity score for this material substance aspect was 0.86, which falls into the very valid category.

The second aspect of the validity instrument is the visual communication display. This aspect consists of five assessment indicators: 1) navigation, 2) fonts, 3) media, 4) color, and 5) layout. The results can be seen in the graph shown in Figure 2.

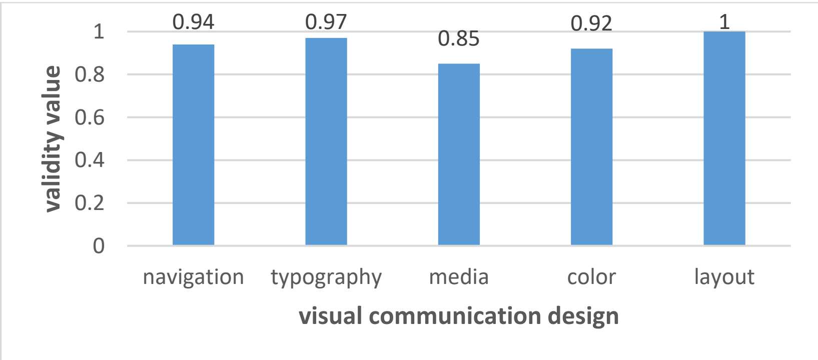

Figure 2. Visual Communication Display Aspect

Based on the results obtained in Figure 2 regarding the visual communication display aspect, the validation results for this aspect ranged from 0.85 to 1. The first indicator, navigation, scored 0.94, categorized as very valid. Furthermore, the second indicator, font, scored 0.97, categorized as very valid. The third indicator, media, scored 0.85, categorized as very valid. The fourth indicator, color, scored 0.92, categorized as very valid. The final indicator, layout, scored 1, categorized as very valid. Thus, the overall average score for this visual communication display aspect was 0.93, categorized as very valid.

The third aspect of the validity instrument is the E-Student Worksheets component. This aspect consists of several assessment indicators: 1) title, 2) learning instructions, 3) achieved competencies, 4) supporting information, 5) tasks and work steps, 6) assessment/evaluation, and 7) references. The validity results can be seen in the graph presented in Figure 3.

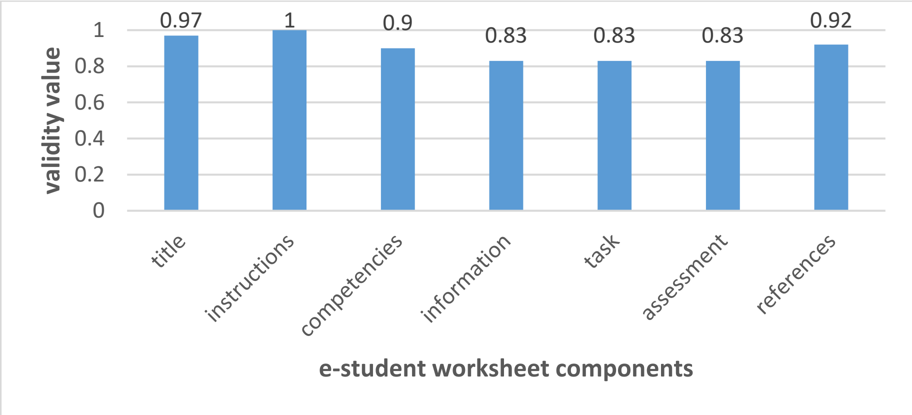

Figure 3. Aspects of E- Student Worksheets Components

Based on the results obtained in Figure 3 regarding the E-Student Worksheets component aspects, the validation results for the E-Student Worksheets component aspects show scores ranging from 0.83 to 1. The first assessment indicator is the title, with a score of 0.97, categorized as very valid. The second indicator is the learning instructions, with a score of 1, categorized as very valid. The third indicator is the achieved competency, with a score of 0.9, categorized as very valid. The fourth indicator is supporting information, with a score of 0.83, categorized as very valid. The fifth indicator is the assignment and work steps, with a score of 0.83, categorized as very valid. Next, the sixth indicator is the assessment/evaluation, with a score of 0.83, categorized as very valid. Finally, the reference indicator received a score of 0.92, categorized as very valid. Overall, the average validity score for the E-Student Worksheets components was 0.92, categorized as very valid.

The fourth aspect of the validity instrument is software utilization. Within this aspect, several assessment indicators are: 1) interactivity (feedback from the system to the user), 2) supporting software, and 3) originality. The validity results obtained in the aspect of software utilization can be seen through the graph presented in Figure 4.

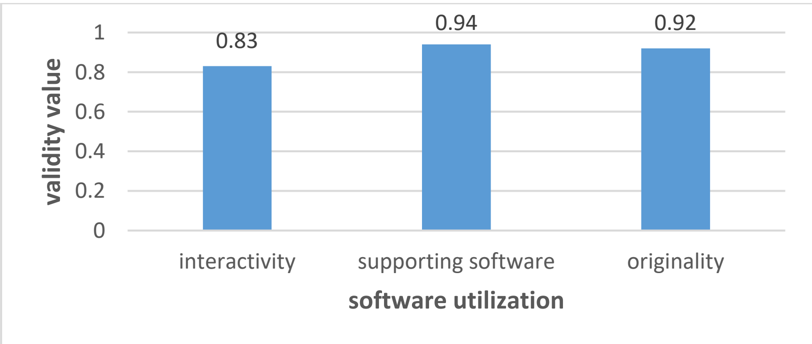

Figure 4. Aspects of software utilization

Based on the results obtained in Figure 4 regarding the software utilization aspect, the validation results for this aspect showed scores between 0.83 and 0.94. The first assessment indicator, interactivity (system feedback to the user), scored 0.83, categorized as very valid. The second indicator, supporting software, scored 0.94, categorized as very valid. Finally, the originality indicator scored 0.92, categorized as very valid. Overall, the software utilization aspect had an average validity score of 0.86, categorized as very valid.

The fifth aspect of the validity instrument is the STEM approach contained in the E-Student Worksheets. This aspect has several assessment points that align with the STEM components: 1) science, 2) technology, 3) engineering, and 4) mathematics. The validity results of the STEM approach components can be seen in the graph presented in Figure 5.

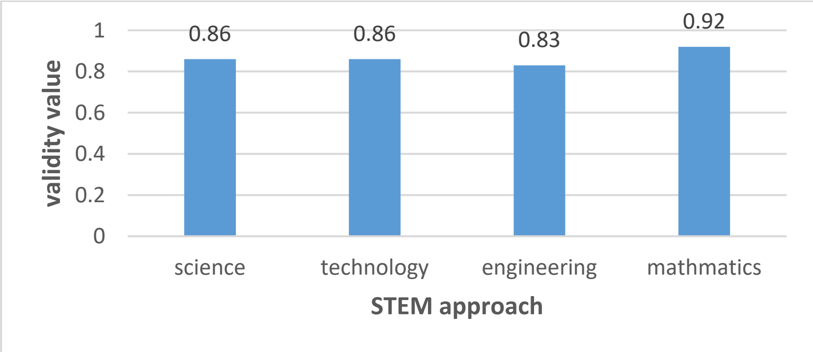

Figure 5. STEM approach

Based on the results obtained in Figure 5 regarding the STEM approach, the validation results showed scores between 0.83 and 0.92. The first STEM component is science, with a score of 0.86, which can be categorized as very valid. Next is technology, with a score of 0.86, which is categorized as very valid. The next STEM component is engineering, with a score of 0.83, which is also categorized as very valid. The final STEM component is mathematics, with a score of 0.92, which is categorized as very valid. Furthermore, the overall average validity score based on the STEM approach aspects was 0.86, making it categorized as very valid.

The sixth aspect of the validity instrument is the problem-based learning model used in the E-Student Worksheets. In this aspect, there are seven assessment items that align with the syntax of the problem-based learning model proposed by Arends. According to (Arends, 2012), there are five syntax indicators included in this problem-based learning model. The validity results for the problem-based learning model components can be seen in the graph presented in Figure 6.

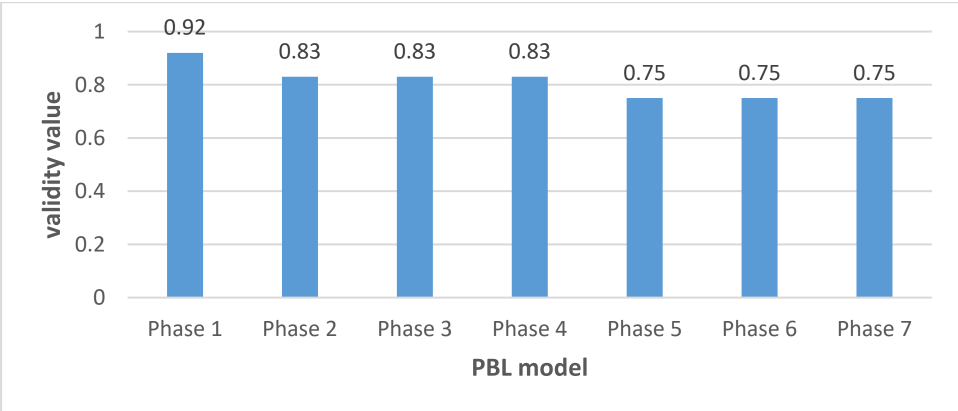

Figure 6. PBL Model

Based on the results obtained in Figure 6, the validity scores for the implementation of the PBL model ranged from 0.75 to 0.92, indicating that all indicators met the validity criteria. The first indicator (Phase 1), which evaluates the suitability of the overall learning process with the PBL model, obtained the highest validity score of 0.92 and was categorized as very valid. The second, third, and fourth indicators (Phase 2 to Phase 4), representing problem orientation, organizing students for learning, and guiding investigations, each obtained a validity score of 0.83, which also falls within the very valid category. Meanwhile, the fifth, sixth, and seventh indicators (Phase 5 to Phase 7), related to developing and presenting work, analyzing and evaluating the problem-solving process, and providing evaluation questions, each obtained a validity score of 0.75 and were categorized as valid. Overall, the average validity score for the implementation of the PBL model was 0.81, indicating that the learning activities incorporated into the E-Student Worksheet were highly consistent with the syntax of the Problem-Based Learning model proposed by Arends (2012).

The final aspect concerns critical thinking skills, as included in the E-Student Worksheets. Within this critical thinking skills aspect, several assessment indicators are: 1) interpretation, 2) analysis, 3) explanation, 4) inference, 5) evaluation, and 6) self-regulation. The validity results for this critical thinking skills aspect can be seen in the graph presented in Figure 7.

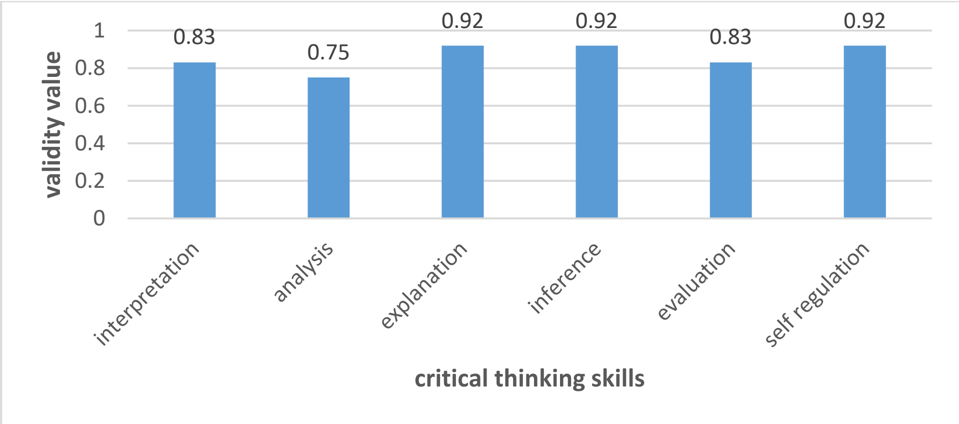

Figure 7. Aspects of Critical Thinking Skills

Based on the results obtained in Figure 7, the validation analysis of the critical thinking skills aspects contained in the E-Student Worksheets showed scores between 0.75 and 0.92. The first assessment indicator is interpretation, with a score of 0.83, which can be categorized as very valid. The second indicator is analysis, with a score of 0.75, and is categorized as valid. The third indicator is explanation, with a validity score of 0.92, and is categorized as very valid. The next indicator is inference, with a validity score of 0.92, and is categorized as very valid. The fifth indicator is evaluation, with a validity score of 0.83, and is categorized as very valid. The final indicator is self-regulation, with a validity score of 0.92, and is categorized as very valid. Overall, for this aspect of critical thinking skills, the average validity score was 0.86. This aspect of critical thinking skills can be considered very valid.

Overall, to assess the validity of the STEM-based E-Student Worksheets with the PBL model, conclusions can be drawn from the seven aspects that received average scores. These aspects include: 1) material substance, 2) visual communication display, 3) E-Student Worksheets components, 4) software utilization, 5) STEM approach, 6) PBL model, and 7) critical thinking skills. Each of these aspects plays an important role in ensuring that the E-Student Worksheets created is able to improve students' knowledge and present electronic teaching materials that are interesting and effective to use. This assessment process aims to determine the validity and feasibility of the E-Student Worksheets in supporting student learning outcomes, especially in facilitating critical thinking skills through the STEM approach with a problem-based learning (PBL) model. High validity scores for all components indicate that the E-Student Worksheets has been well-structured. The following are the results of the average validity scores for all components presented in graphical form as seen in Figure 8.

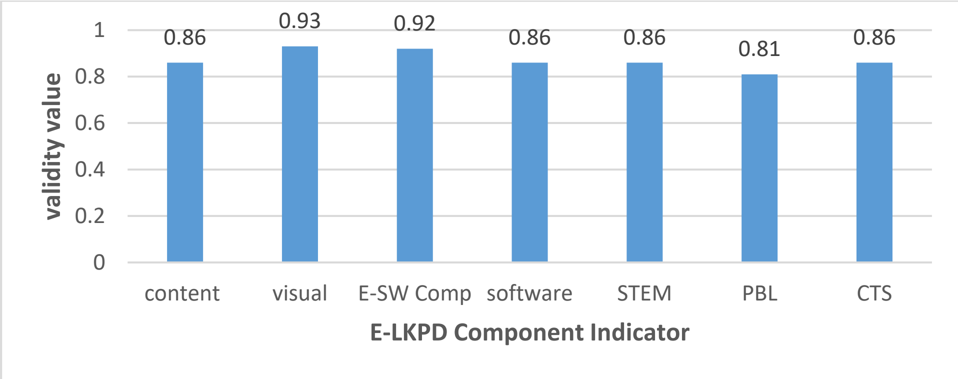

Figure 8. Overall validity score of E-Student Worksheets assessment aspects

Based on Figure 8, it can be concluded that the STEM-based E-Student Worksheets with the PBL model developed to facilitate students' critical thinking skills obtained a high validity value for each component. When viewed based on the assessment aspects, the material substance aspect obtained a result of 0.86 which is categorized as very valid; the visual communication display aspect obtained a result of 0.93 which is categorized as very valid; the E-Student Worksheets component aspect obtained a result of 0.92 which is categorized as very valid; the software utilization aspect obtained a result of 0.86 which is categorized as very valid; the STEM approach aspect obtained a result of 0.86 which is categorized as very valid; the problem-based learning (PBL) model aspect obtained a result of 0.81 which is categorized as very valid; and the critical thinking skills aspect obtained a result of 0.86 which is also categorized as very valid.

Discussion

The validation results of the STEM-based E-Student Worksheets using the PBL model for momentum and impulse showed that the product met the eligibility criteria in several aspects: 1) material substance, 2) visual communication display, 3) E-Student Worksheets components, 4) software utilization, 5) STEM approach, 6) PBL model, and 7) critical thinking skills. The assessment components used were based on the 2010 standards of the Directorate of High School Development. The validation process was conducted in a structured manner by three experts, both Physics lecturers from Padang State University. Based on the assessment results, the E-Student Worksheets obtained an average score in the "very valid" category, indicating that the product met the validity requirements for learning activities. This validity reflects that the material aligns with the curriculum, the learning steps align with PBL objectives, the instructional sequence facilitates active engagement, and the E-Student Worksheets has an attractive visual display and is easily accessible to students.

The first aspect assessed in this E-Student Worksheets was the material substance. The assessment results showed a validity score in the "very valid" category. This indicates that the E-Student Worksheets has met the eligibility criteria in terms of material substance. The second aspect is the visual communication display. The assessment results show a validity value in the "very valid" category. In this case, the E-Student Worksheets also shows good criteria related to the visual communication display. The third aspect is the learning design, which in this case refers to the components of the E-Student Worksheets. The fourth aspect is software utilization. The assessment results show a validity value in the "very valid" category. This indicates that the E-Student Worksheets has met the eligibility criteria related to the software used. The next aspect is the STEM approach. The assessment results show a validity value in the "very valid" category. This indicates that the E-Student Worksheets has met the eligibility criteria in terms of the STEM approach aspect applied in it. The sixth aspect is the problem-based learning model. The assessment results show a validity value categorized as "very valid". This indicates that the E-Student Worksheets has met the E-Student Worksheets criteria from the aspect of the problem-based learning model contained therein. The final aspect is critical thinking skills. The assessment results show a validity value categorized as "very valid". This indicates that the E-Student Worksheets meets the criteria for critical thinking skills, including helping students achieve the expected competencies.

Based on the description of the research results, we obtained a development product and data regarding the validity level of the STEM-based E-Student Worksheets with the PBL model on momentum and impulse, which facilitates students' critical thinking skills. This validity value was obtained after analyzing the data using the Aiken index; if it meets the criteria, the E-Student Worksheets can be declared very valid. This research aligns with previous research that states that a teaching material is valid if it has a score of ≥ 0.6 (Ramli et al., 2020). This E-Student Worksheets product is equipped with supporting information, images, videos, experiments, and practice questions. The STEM-based E-Student Worksheets with the PBL model facilitates students' critical thinking skills. Through the STEM components and PBL syntax, students can discover physics concepts for themselves and relate them to real-world events. The presentation of the E-Student Worksheets, complemented by images and videos, also helps students better understand the learning material. The provided practice questions also facilitate students' critical thinking skills. This is in line with previous research showing that the use of PBL-STEM can facilitate students' critical thinking skills (Wahdaniyah et al., 2023). In addition, there is also research stating that the implementation of STEM-based E-Student Worksheets can facilitate students' critical thinking skills (Milala et al., 2024). This E-Student Worksheets is presented in an online format so that teachers and students can access it via mobile phones or laptops. The developed E-Student Worksheets is also more interactive because it uses the Live worksheets platform. This is relevant to previous research showing that the use of Live worksheets-based E-Student Worksheets can arouse students' interest in learning, as evidenced by the high level of student interest in the learning process (Mudaim et al., 2023).

Validation of the STEM-based E-Student Worksheets with the PBL model on momentum and impulse material to facilitate students' critical thinking skills was carried out with three expert lecturers from the Physics Department, FMIPA UNP. The product validation results showed an average value of 0.87 which is included in the very valid category. A product can be said to be valid if it is in accordance with the established reference structure. These results indicate that this E-Student Worksheets has met all indicators in the validation assessment aspect. Referring to previous research, the validation process by lecturers or experts not only produces a score, but also includes improvements through suggestions and comments on the developed product, so that the final product is suitable for use (Lasiani et al., 2025). Based on these results, it can be concluded that this E-Student Worksheets is not only theoretically and practically feasible, but also has great potential in facilitating students' critical thinking skills. The integration of interactive digital media with the STEM approach and problem-solving makes the learning experience more contextual, relevant, and enjoyable. Therefore, the implementation of this kind of E-Student Worksheets is highly recommended not only for momentum and impulse material, but can also be adapted for other physics materials and similar science lessons to support learning transformation that is responsive to the challenges of the 21st century.

CONCLUSION

Based on the results of this study, the STEM-based E-Student Worksheet integrated with the Problem-Based Learning (PBL) model achieved an average validity index of 0.87, which is classified as very valid. This result indicates that the developed teaching material satisfies the established validity criteria and is considered appropriate for use in physics learning on the topic of momentum and impulse. The high validity score demonstrates that the product fulfils all assessment aspects, including material substance, visual communication, E-Student Worksheet components, software utilization, STEM integration, PBL implementation, and critical thinking indicators. These findings suggest that the developed E-Student Worksheet is suitable as a digital teaching material to support the implementation of the Merdeka Curriculum and to facilitate student-centered learning. Therefore, the developed E-Student Worksheet has the potential to serve as an innovative technology-based learning resource that supports the development of students' critical thinking skills. Further research is recommended to evaluate the practicality and effectiveness of the product in improving students' learning outcomes and critical thinking skills in classroom implementation.

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