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Design of STEM-based E-Student Worksheet Global Warming to Improve High School Students' Critical Thinking Skills

Sahri Ropiah Lubis[1], Selma Riyasni[2*], Yurnetti[3], Fuja Novitra[4]
[1,2,3,4] Department of Physics, Padang State University, Padang, Indonesia.

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ABSTRACT

This research was motivated by the importance of critical thinking skills in understanding environmental issues such as global warming. Preliminary findings showed that the critical thinking skills of Grade X students at SMAN 3 Padang were still low, reaching only 29.67%. Learning also remained limited to the use of student worksheets that were not STEM-based and lacked optimal technology integration. This study aimed to develop a STEM-integrated E-student worksheet to support interactive learning and improve students' critical thinking skills. The study used a Research and Development (R&D) method with the 4-D model (Define, Design, Develop, Disseminate), limited to the Develop stage. The product was created using Liveworksheets and validated by experts, physics teachers, and students. The expert validation achieved an average score of 0.94 (valid), covering material substance (0.95), instructional design (0.96), visual communication (0.98), software use (0.87), STEM assessment (0.91), and critical thinking assessment (0.95). Practicality tests resulted in 95% from teachers and 92% from students, categorized as very practical. Thus, the STEM-based E-student worksheet is valid, practical, and potentially improves students' critical thinking skills.

***Correspondence:**
Selma Riyasni, Department of Physics, Padang State University, Padang, Indonesia.
· Email: Selma.r@fmipa.unp.ac.id

INTRODUCTION

The development of education in the 21st century requires students to master a range of competencies, including creativity, collaboration, communication, and critical thinking (Bani et al., 2025). These competencies are strengthened through the implementation of the Independent Curriculum, which encourages teachers to design learning activities that are adaptive to students' needs and characteristics (Tunas & Pangkey, 2024). Learning is expected to be student-centered, contextual, and oriented toward the development of higher-order thinking skills. Through project-based learning, students are guided to explore real-world problems and connect them with scientific concepts (Rizky Saria et al., 2022). Thus, education is no longer focused solely on the delivery of theoretical knowledge, but also on

shaping intellectual and character competencies required for global competition.

Critical thinking is one of the essential skills that must be developed in physics learning because it enables students to analyze information, evaluate arguments, and solve problems logically (Khairiyah et al., 2023). Learners with strong critical thinking skills tend to understand concepts more deeply and are capable of making rational decisions based on evidence (Sinaga et al., 2022). Physics learning, therefore, should not only convey theoretical concepts but also train students to relate physical phenomena to scientific principles and apply them in everyday life (Harefa, 2019). For this reason, learning media should be designed to stimulate reasoning, interpretation, inference, and explanation so that critical thinking can grow naturally through the learning process.

The integration of technology in learning has also become increasingly important as digital media offer flexibility, interactivity, and accessibility (Magdalena et al., 2020). Electronic-based teaching materials enable students to learn independently, explore multimedia resources, and interact more dynamically with content (Zahara et al., 2021). One learning medium that supports this goal is the Student Worksheet (SWS), which facilitates students in observing, analyzing, and constructing concepts systematically (Putriyana et al., 2020). When developed in an electronic format (E-SWS), it becomes more engaging, interactive, and aligned with digital learning trends (Yulanda et al., 2023). Thus, the use of technology-based SWS is essential to support meaningful learning and improve students' cognitive development.

Several previous studies have developed STEM-based Student Worksheets on various topics, such as elasticity (Hasanah & Budhi, 2023), static fluids (Lestari & Muhajir, 2021), and the excretory system (Fithri et al., 2021). However, research that specifically develops a STEM-based Electronic Student Worksheet (E-SWS) on global warming material aimed at improving critical thinking skills is still limited. Most existing worksheets remain in printed form and have not yet optimized digital features that support interactive physics learning. Moreover, critical thinking indicators—particularly inference and evaluation—were reported to be relatively low (Fitriyah & Madlazim, 2021), indicating the need for innovative teaching media that stimulate deeper analytical engagement. Therefore, this study aims to develop a STEM-based Electronic Student Worksheet (E-SWS) on global warming that is valid, practical, and potentially effective in improving high school students' critical thinking skills through interactive and technology-supported learning.

METHODS

This research employed the Research and Development (R&D) method with the objective of producing a STEM-based Electronic Student Worksheet (E-SWS) on global warming to improve the critical thinking skills of high school students. The development model used was the 4-D model (Define, Design, Develop, Disseminate) developed by Thiagarajan (1976). The stages include defining needs, designing product prototypes, developing and validating products, and disseminating final products. However, this study was limited only to the Develop stage due to time and research scope limitations. The R&D method was selected to ensure that the product developed was feasible and appropriate for classroom learning use.

Figure 1. Stages of 4-D Model

The main variable in this study was the STEM-based E-SWS developed as a learning product on global warming material. Supporting variables consisted of validity and practicality values obtained during product evaluation. Validity indicators included material suitability, design, visual communication, software utilization, STEM assessment, and critical thinking components. Practicality indicators measured ease of use, clarity, attractiveness, and usefulness during learning implementation. These variables served as parameters for determining product quality before its application in broader learning settings.

The research subject was Grade X students of SMAN 3 Padang in the even semester who studied global warming material, while the research object was the STEM-based E-SWS developed for physics learning. Product validation involved three expert validators consisting of a material expert, media expert, and physics teacher. Practicality data were collected from one teacher and a group of students through trials. The selection of research subjects was based on curriculum suitability and accessibility for digital-based learning implementation. Data collection was conducted during February 2025.

The development process followed three stages of the 4-D model: Define, Design, and Develop. The Define stage involved analyzing curriculum needs, student characteristics, and learning objectives. The Design stage consisted of arranging content structure, developing learning activities, and designing the digital worksheet format. The Develop stage included product creation using Liveworksheets, validation by experts, revisions based on validator feedback, and practicality testing with teachers and students. The Disseminate stage was not carried out due to research limitations.

Data were collected using expert validation sheets and practicality questionnaires with a 4-point Likert scale. Validation sheets assessed content quality, media appropriateness, visual design, software usage, STEM alignment, and critical thinking indicators. Practicality questionnaires measured user response regarding clarity, attractiveness, ease of use, and effectiveness of the E-SWS. The Likert scale conversion allowed the assessment results to be interpreted descriptively into percentage form. Documentation was also used to support research data authenticity.

$$Validity\ Value = \frac{Skor\ obtained}{Maximum\ score} \times 100\%$$

The validator's assessment of each of the assessed questions was then analyzed using Aiken's V formula.

Aiken's formula is as follows:

$$V = \frac{\Sigma S}{[n(c-1)]}$$
$$s = r - lo$$

(Aiken, 1985)

Information:

V = Validity Index
Lo = lowest score (in this study it was 1)
c = highest rating figure
r = number provided by validator
n = many validators
S = sum of the total values of all validators

The assessment of the validation results of STEM-based electronic E-SWS on global warming was determined based on the interpretation of Aikens's V validation as shown in Table 1.

Table 1. Interpretation of Aiken's V Validation

Interval	Valid Categories
V ≤ 0.4	Less
0.4 < V ≤ 0.8	Keep
0.8 < V	Tall

(Retnawati, 2016)

The level of practicality of the product related to its use in the collected data class was analyzed using the criteria score on the assessment questionnaire with *a Likert scale* of 1-4. This analysis technique is used to convert the questionnaire results data into a descriptive form of percentage.

$$Practical\ Value = \frac{Skor\ obtained}{Maximum\ score} \times 100\%$$

The practicality assessment is determined based on the interpretation criteria of the score obtained as Table 2.

Table 2. Practicality Criteria

Interval %	Category
0-20	Very Impractical
21-40	Impractical
41-60	Less Practical
61-80	Practical
81-100	Very Practical

(Sugiyono, 2022)

RESULTS AND DISCUSSION

Results

Define Stage

Based on the Define stage, it was found that physics learning still requires interactive media that supports the STEM approach to foster students' critical thinking skills. The analysis of students' abilities showed that the average critical thinking score was only 29.67%, with explanation (25.76%) and inference (25%) being the lowest indicators, indicating that students are not yet able to provide arguments or draw conclusions based on evidence. The detailed results of students' critical thinking skills can be seen in Figure 2, which shows that all indicators are still categorized as low.

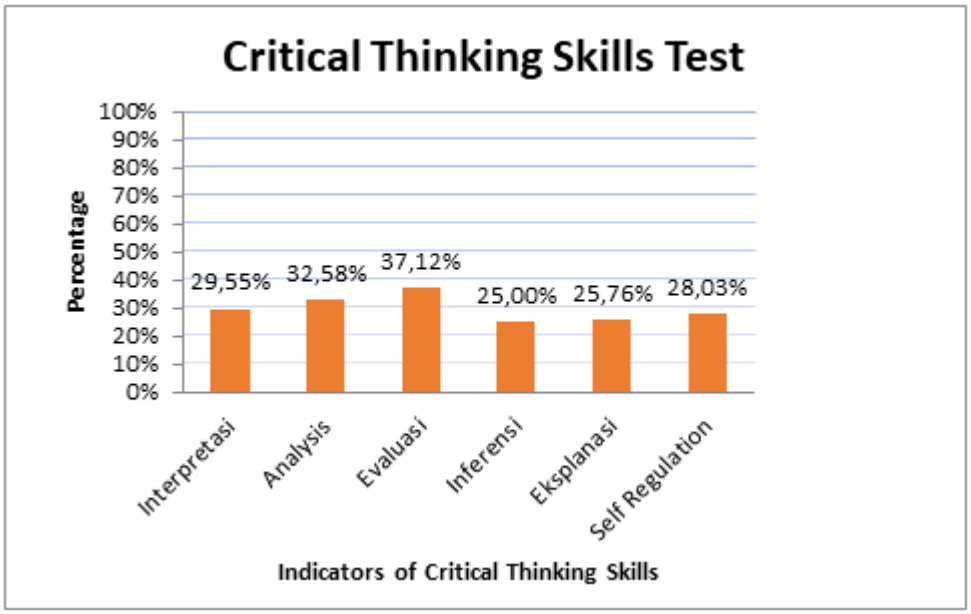

Figure 2. Critical Thinking Skills Test Results

Document analysis also revealed that the integration of technology and engineering aspects reached only 63.8%, indicating that technology use in learning is not yet optimal and still conventional. These findings imply that digital learning media are needed to facilitate exploration, analysis, and problem-solving activities. Moreover, global warming is a relevant context to integrate with the STEM framework because it is directly related to real-world environmental issues. Therefore, the development of a STEM-based Electronic Student Worksheet (E-SWS) is considered necessary to enhance student engagement and support the development of critical thinking skills through science, technology, engineering, and mathematics-based learning.

Design Stage

The design stage focused on constructing the product based on the needs identified in the Define phase. In this stage, the structure, content flow, interface layout, and visual elements of the STEM-based Electronic Student Worksheet (E-SWS) were designed. The final structure of the E-SWS consists of a cover page, introduction, table of contents, usage instructions, competencies and learning objectives, STEM orientation sheet, supporting materials, student activity steps, worksheet section, assessment rubric, bibliography, and author identity. Each component was arranged by considering readability, clarity of instructions, visual attractiveness, and digital interactivity. The final product design can be seen in Figure 3, which presents the layout structure and arrangement of page components of the E-SWS.

Figure 3. Design of Cover and Menu of the E-Student Worksheet

The design also incorporates 21st-century learning characteristics through problem-based activities, higher-order thinking prompts, and multimedia integration. These elements are intended to create learning experiences that encourage students to explore concepts more deeply and connect them with real-world phenomena. The use of multimedia and interactive features helps make the material more engaging and easier for students to understand. In addition, the problem-based structure guides students to analyze information, reason logically, and develop solutions independently. Therefore, the developed E-SWS is visually appealing, interactive, and relevant to STEM-based learning needs, enabling students to engage actively and improve their critical thinking skills.

Develop Stage

The development stage is carried out to test and refine the product that has been designed. At this stage, design validation was conducted by three experts (validators) to assess the feasibility of the content, appearance, and suitability of the STEM-based Electronic Student Worksheet (E-SWS) components. The validation results were then used as the basis for revising the design according to suggestions and feedback provided by the experts. Afterward, product trials were conducted through practicality assessments involving physics teachers and students to determine the level of practicality, effectiveness, and potential of the E-SWS in improving students' critical thinking skills during learning.

Validity Test Results

The validation process was carried out to determine the feasibility of the STEM-based Electronic Student Worksheet (E-SWS) before being tested in the classroom. The validation was conducted by three experts who assessed the product based on material substance, learning design, visual communication, software utilization, STEM integration, and critical thinking assessment components. The validation results were then analyzed using Aiken's V formula to determine the level of validity of each component. The complete results of the validation analysis can be seen in Table 3.

Table 3. Results of the Analysis of the Average Value of E-Student Worksheet Validity

Validation Components	Average (V)	Category
Substance Matter	0.95	Valid
Learning Design	0.96	Valid
Visual Communication Media	0.98	Valid
Software Utilization	0.87	Valid
STEM Assessment	0.91	Valid
Critical Thinking Skills Assessment	0.95	Valid
Average	**0.94**	**Valid**

Based on Table 3, the validation results of the STEM-based E-SWS indicate that all components achieved an average score categorized as valid. The highest score was obtained in the visual communication media component with a value of 0.98, followed by learning design (0.96), material substance and critical thinking skills assessment (0.95), STEM assessment (0.91), and software utilization (0.87). These findings demonstrate that the developed E-SWS meets the eligibility criteria in terms of content quality, learning design, visual presentation, and STEM integration. Therefore, the product is considered suitable for use and has the potential to support the enhancement of students' critical thinking skills in physics learning.

Practicality Test Results

The practicality test was conducted to determine the usability of the STEM-based Electronic Student Worksheet (E-SWS) when applied in learning. This assessment involved physics teachers who evaluated the product based on benefit, ease of use, attractiveness, clarity, and cost-effectiveness. The practicality scores were then converted into percentages to determine the level of practicality of each component. The results of the teacher practicality analysis are presented in Table 4.

Table 4. Results of Analysis of Average Scores of Teacher Practicality

Components of Practicalization	Average Percentage (%)	Category
Benefit	90	Very Practical
Ease of Use	93	Very Practical
The Attractiveness of the Dish	94	Very Practical
Clarity	99	Very Practical
Cost-effective	100	Very Practical
Average	**95**	**Very Practical**

Based on Table 4, the practicality test results show that the STEM-based E-SWS is categorized as very practical with an average score of 95%. All practicality components received high ratings, with the highest value found in the cost-effective aspect (100%), indicating that the product can be used without requiring additional high-cost resources. The clarity component also obtained a very high score of 99%, suggesting that instructions and content in the E-SWS are easy to understand by teachers and potentially by students as well. The attractiveness of the presentation (94%) and ease of use (93%) reflect that the interface, layout, and navigation are user-friendly and engaging. Meanwhile, the benefit component reached 90%, showing that teachers perceive the E-SWS as helpful in supporting learning activities. These results confirm that the E-SWS is practical, efficient, and ready to be

implemented in physics learning to facilitate student engagement and improve critical thinking skills.

The practicality assessment was also carried out by students to determine their response toward the use of the STEM-based Electronic Student Worksheet (E-SWS) in learning. This stage aims to evaluate the usability, clarity, convenience, and attractiveness of the product from the user perspective. The data obtained were analyzed in percentage form to determine the practicality category of each component. The results of the students' practicality analysis are presented in Table 5.

Table 5. Results of Analysis of Average Scores of Students' Practicality

Components of Practicalization	Average Percentage (%)	Category
Benefit	93	Very Practical
Ease of Use	93	Very Practical
The Attractiveness of the Dish	92	Very Practical
Clarity	91	Very Practical
Cost-effective	91	Very Practical
Average	**92**	**Very Practical**

Based on Table 5, the results of the practicality analysis by students show that the STEM-based E-SWS falls into the very practical category with an average score of 92%. All practicality components received high ratings, indicating that students can understand and operate the E-SWS easily during learning. The highest scores were obtained in the benefit and ease of use components (93%), showing that students feel the product is useful and simple to navigate. The attractiveness component also achieved a high score (92%), suggesting that the visual design and layout are engaging and motivating for learning. In addition, the clarity and cost-effective components reached 91%, which means the instructions and content are understandable and do not require additional costs for use. These results demonstrate that the developed E-SWS is user-friendly, visually appealing, and efficient, making it highly suitable to support learning activities and encourage the improvement of students' critical thinking skills.

Discussion

The creation of STEM-based E-SWS on global warming to improve critical thinking skills is motivated by the problem of low critical thinking skills of students at SMAN 3 Padang, as well as the available teaching materials still need to be improved to be more interesting, interactive, and technology-based in order to increase learning engagement. The results of the study show that the e-student worksheet developed has met valid and practical criteria, so it is suitable for use as an alternative to innovative teaching materials in physics learning.

The results of the validity test conducted by three experts using Aiken's V analysis showed that the six components of the assessment, namely material substance (0.90), learning design (0.88), visual communication display (0.89), software utilization (0.87), STEM assessment (0.88), and critical thinking skills assessment (0.91) were included in the valid category. A high score on the substance of the material indicates that the content of the student worksheet has met the criteria of concept correctness, scope, contemporaneity, and readability according to learning needs. The learning design is also prepared systematically from the introduction to the evaluation, showing conformity with the principles of good teaching material preparation. Meanwhile, the attractive display of visual communication

has been shown to help clarify abstract concepts and increase learners' motivation to learn. This is in line with the findings of Furqoniyah et al. (2022) who stated that interactive visual design can strengthen students' conceptual understanding. The use of *Liveworksheets* software is also considered effective in creating an interactive learning experience, supporting flexibility and time efficiency as evidenced by research by Hasanah & Budhi (2023). The integration of *Science, Technology, Engineering,* and *Mathematics* (STEM) in the student worksheet is going well, although the technology and engineering elements still need to be further developed. This finding is consistent with Fithri et al. (2021) who stated that the application of STEM approaches plays an important role in developing students' critical thinking skills. In addition, all indicators of critical thinking skills according to Facione (2015) including interpretation, analysis, evaluation, inference, explanation, and *self-regulation* have been accommodated in learning activities that are arranged in an integrated manner. These results reinforce the findings of Salsabilla et al. (2024) and Fitriyah & Madlazim (2021) who show that STEM-based student worksheet has a significant effect on improving students' critical thinking skills. Thus, the electronic LKPD developed is declared valid in terms of content, design, display, and use of digital media.

Furthermore, the results of the practicality test conducted by teachers and students showed that the student worksheet had a very high level of practicality. Assessments from teachers obtained an average of 95%, which included aspects of benefits, ease of use, attractiveness of presentations, clarity, and cost efficiency. These results show that student worksheet is easy to implement, visually appealing, and able to help teachers explain the concept of global warming in a simpler and more meaningful way. These findings are in line with Hasanah & Budhi (2023) who affirm that digital media can increase the effectiveness and efficiency of learning. Meanwhile, the assessment of students obtained an average of 92%, which is also in the category of very practical. Students assessed that this student worksheet is easy to use, interesting, clear, and useful because it helps them understand the concept of global warming in depth through interactive activities. These results support the research of Salsabilla et al. (2024) and Fithri et al. (2021) which show that STEM-based student worksheet can increase students' motivation, engagement, and critical thinking skills.

Overall, the STEM-based Electronic Student Worksheet (E-SWS) developed in this study has been proven to be valid and practical based on expert validation and user practicality tests. The product is feasible to use in learning with strong aspects of content quality, design, visual presentation, and digital-based functionality. Each activity within the E-SWS is structured according to the stages of the STEM approach and integrated with critical thinking indicators, allowing students to analyze, evaluate, and solve contextual problems. This integration provides an interactive and meaningful learning experience that supports the development of students' reasoning skills. Thus, the E-SWS has great potential to be implemented as an effective learning media to enhance students' critical thinking abilities.

However, this study has some limitations. The *feedback* feature on the *Liveworksheets* platform is still simple, so it is not yet able to provide automatic responses to student mistakes. In addition, product trials are still limited to one school, so further research on a broader scale is needed to strengthen the generalization of results. In the future, development can be directed at the use of digital platforms with interactive feedback features and integration of real problem-based projects that emphasize technology and engineering aspects so that STEM-based learning becomes more applicable and contextual.

CONCLUSION

Based on the results of the study, the STEM-based Electronic Student Worksheet (E-SWS) on global warming was successfully developed and categorized as valid and practical, making it feasible for use in class X physics learning. The validation results show that all components meet the eligibility criteria in terms of material, design, visual quality, and STEM integration. The practicality test also indicates that teachers and students responded positively to the E-SWS, proving that the product is easy to use, attractive, and efficient in learning activities. Learning activities designed in the E-SWS follow the STEM stages and are linked to critical thinking indicators, encouraging students to analyze, evaluate, and solve contextual problems independently. This condition supports meaningful learning and facilitates the development of higher-order thinking skills. Therefore, the developed E-SWS has the potential to improve students' critical thinking skills and conceptual understanding in global warming material. Future implementation and testing in a broader learning context are recommended to measure its effectiveness on learning outcomes more comprehensively.

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