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STEM-Based Physics Modules with CK-12 Simulations for High School Students: Development and Implementation

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Abstract

Research has been conducted to develop STEM-based physics modules with CK-12 simulations for high school students. This study evaluates the STEM-based physics module's validity, practicality, and effectiveness with CK-12 simulations for grade X students. The research employed research and development (R&D), utilizing the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. The study involved three expert validators and students from two schools to assess the module's validity, practicality, and effectiveness. The participants comprised grades X MIA students from SMAN 1 Alu and X IPA students from MAN 2 Polewali Mandar. The validity of the developed physics modules, presented as a practical module, was assessed through expert validation, while practicality was evaluated using response questionnaires completed by students and teachers. Effectiveness was determined based on student learning outcome tests. The results indicate that the physics module was highly valid, with an overall validity score of 87.78%. Practicality was also rated highly, with scores of 90.29% from students and 99.00% from teachers. Furthermore, the module demonstrated effectiveness, as evidenced by student learning outcomes meeting the established criteria, with an effectiveness score of 79.17%. These findings suggest that STEM-based physics modules with CK-12 simulations can significantly enhance the quality of physics teaching and learning for high school students. In addition, this research should be explored for other topics.

Keywords: physics module, CK-12 simulations, STEM, research and development

INTRODUCTION

Natural science is a collection of knowledge that studies natural phenomena, including physics, chemistry, and biology. Physics is the branch of science that studies the properties and phenomena of nature and the interactions that occur within it, which humans can observe (Oktaviana, Putri & Risdianto, 2020). Concerning the definition of physics, (Sholikhah & Sucahyo, 2021) argue that physics is a branch of natural science that studies various phenomena or events around us. In other words, physics is a field of knowledge closely related to human daily life and can be observed by humans.

Learning physics is not sufficient by just knowing and understanding concepts or theories; further proof is required through practical activities (Alexandru & Singh, 2024). Physics is a body of knowledge based on facts, the results of experts' reasoning, and the experiments conducted by these experts (Musdar, 2020; Mastuti, Nurlina & Mutmainna, 2022). Physics learning is closely related to physics practical work because physics lessons are full of theories, laws, principles, concepts, and rules about physics, all of which need to be validated through practical work (Sarjono, 2018; Neumann et al., 2021). According to the Indonesian Dictionary (KBBI), practical work is part of the teaching process that allows students to test and apply what they have learned in theory in real-life situations. The practical method in the learning process will enable students to experience or perform tasks themselves, follow a process, observe an object, analyze, validate, and draw conclusions about a particular object, condition, or process (Suryaningsih, 2017). Through practical activities, students can conduct simple investigations, gain firsthand experience through observations, and engage in discussions (Nasution, 2010). Without practical activities, students would only be at the level of knowing theories without any proof process, thus limiting their knowledge and preventing the development of their skills. Physics is a subject that is directly related to practical work to test physics theories or concepts. Still, during laboratory tests/practical work, minor accidents are sometimes challenging to deal with, such as equipment not functioning/being damaged (Rosmiati & Nurlina, 2022). Therefore, in physics learning, conducting practical work is essential (Knewstubb,2014).

Implementing physics practical work in schools is closely related to using laboratory spaces. The physics laboratory in schools contains various facilities that support practical physics activities (Sarjono, 2018). Therefore, one of the key factors in successfully implementing physics practical work in schools is the availability of adequate laboratory facilities. Based on observations at SMAN 1 Alu during the Teaching Assistance Program of the Faculty of Teacher Training and Education at the Universitas Sulawesi Barat in 2021, it was found that physics practical activities are still rarely conducted. Practical work is usually only done in the classroom using simple tools or equipment from other schools. This is due to the inadequacy of laboratory facilities, such as the lack of available practical equipment and the repurposing of the existing laboratory space into a classroom.

In addressing this issue, an alternative approach is needed to conduct physics practicals in schools. One possible way is to carry out practicals using online simulations. This aligns with the opinion of (Abdi, Mustafa & Pada, 2021), who stated that teachers can utilize technology to overcome practical issues that cannot be conducted conventionally. (Abdi, Mustafa & Pada, 2021) Arun and Mohit also quoted, who said that practicals can be performed virtually using computers supported by learning simulations. At SMAN1 Alu, a computer laboratory is equipped with Wi-Fi facilities, making online practicals a feasible solution.

Many interactive simulations can be used to conduct online practicals, including the CK-12 simulation. As a nonprofit educational organization, CK-12 was founded in 2007 by Neeru Khosla and Murugan Pal. CK-12 was established to allow everyone to learn in their way, providing high-quality content with the latest technology and equipping students, teachers, and parents with everything they need (Farah et al., 2021; Schiering, 2021). CK-12 offers free educational content through a web-based platform called “FlexBook.” This website has many textbooks on various topics, learning videos, practice questions, quizzes, simulations, a toolbar that teachers can use to create study groups with students, and other features. (Farah et al., 2021) stated that the CK-12 website is a virtual learning site believed to have the potential for widespread use in teaching and learning.

The CK-12 website provides many physics simulations that can be used to conduct online practicals. The physics simulations on the CK-12 website have the advantage of presenting scenarios often encountered daily. One example is the simulation for projectile motion, which is displayed as a fountain. This way of presentation helps students better experience the application of physics concepts in everyday life. In addition to this advantage, there are several other benefits, including an attractive interface, easy accessibility, and, of course, being free. Concepts, tutorial videos, and worksheets also accompany each simulation. However, an online search on CK-12 reveals that there is still minimal discussion and research on this platform. Due to its limited use and considering the advantages of the CK-12 simulation, the researcher chose this simulation. A scientific study using CK-12 simulations in physics examines the relationship between analytical thinking skills and scientific argumentation in physics education. The results indicate that students’ analytical thinking skills and scientific argumentation (Perdana, Jumadi & Rosana, 2019).

CK-12 simulations offer numerous benefits in physics education; however, their integration with STEM-based practical modules has been minimally explored in physics teaching. Implementing online practicals using the CK-12 simulation requires practical equipment to support school practical activities. However, at SMAN 1 Alu, such equipment is not yet available. The necessary practical equipment includes practical modules with lesson plans (RPP) and learning outcome tests as supporting tools for using or implementing these modules. A practical module is a guide for students and teachers to conduct practicals. The lesson plan is intended to provide an overview of the learning process to be carried out. In contrast, the learning outcome test aims to assess the student's abilities after the learning process.

Using physics practical modules supported by CK-12 simulations can be integrated with an approach that aligns with the current educational demands, aiming to enhance the quality of education. One such approach is the STEM framework. Traditionally, the STEM classroom laboratory encourages active participation from all students in learning, reflecting the scientific methodology used within a research community (Rosen & Kelly, 2023). Highlighting the importance of values in STEM education can improve comprehension of technoscientific advancements' social and ethical dimensions. Explicitly addressing these values enables educators, parents, institutions, and policymakers to inspire students to engage with the ethical aspects of science, fostering a more responsible and holistic approach to STEM (Christian et al., 2021; Vedrenne-Gutiérrez et al., 2024). STEM practice encourages students to explore innovative ideas, concepts, and processes that address the needs of the 21st century (Kencana, Musri & Syukri, 2020; Darmawansah et al., 2023).

According to an interview with a physics teacher at SMAN 1 Alu, this STEM approach has not yet been implemented in the physics instruction at the school. STEM (Science, Technology, Engineering, and Mathematics) is an innovative educational approach that integrates multiple disciplines (Santoso & Mosik, 2019). It is a pedagogical model that combines science, technology, engineering, and mathematics, which is believed to foster the development of 21st-century competencies (White, 2023). These competencies include creativity, critical thinking, collaboration, and communication (Ketang et al., 2022). Therefore, adopting this approach is expected to support the development of these four essential skills in learners.

STEM learning is an approach that aligns with the 2013 curriculum, which emphasizes the learning process to help students understand various materials through a scientific approach (Mahjatia, Susilowati & Miriam, 2021). In addition, STEM is also a multidisciplinary learning approach that can support the goals of the Merdeka curriculum, which provides students with the opportunity to learn across disciplines independently and creatively while prioritizing character development (Putri, 2021). Research by Yildirim and Altun states that the STEM approach can create practical and high-quality learning, linking it to real-life experiences and developing higher-order thinking skills (Yildirim, 2016). (Mahjatia, Susilowati & Miriam, 2021), Khoiriyah and Husamah assert that STEM is an educational approach that connects real-world applications with classroom learning across STEM fields.

The research conducted by (Sari, 2021) concluded that developing the basic Physics 1 e-module with a STEM approach met the feasibility, practicality, and effectiveness criteria, making it suitable for basic Physics 1 laboratory activities. Additionally, the findings of (Abdi, Mustafa & Pada, 2021) indicated that implementing the STEM approach based on PhET simulations could enhance students' understanding of physics concepts. Another study by (Sukmagati, Yulianti & Sugianto, 2020) concluded that the feasibility test using a questionnaire showed that the STEM-based student worksheets (LKS) were classified as highly feasible for use, while the readability test using a cloze test showed that the STEM-based LKS were easy to understand. Furthermore, the improvement in pretest to posttest scores demonstrated that the STEM-based LKS could enhance students' creative thinking abilities. The researcher is interested in conducting development research by developing a practical tool, in this case, a physics practical module integrated with CK-12 simulation based on STEM.

METHODS

The type of research used is research and development (R&D). The R&D method can be defined as a scientific approach to researching, designing, producing, and testing the validity of developed products (Sugiyono, 2022). The product developed in this research is a practical tool in the form of a physics practical module assisted by CK-12 simulation based on STEM for grade X MIA.

The development model used in this study is the ADDIE development model. ADDIE stands for Analysis, Design, Development, Implementation, and Evaluation. (Soesilo & Munthe, 2020), quoting Piskurich, states that the ADDIE development model has advantages, namely being simple, systematic, and widely used in creating effective learning programs and products that experts validate. The concept of the ADDIE development model can be seen in FIGURE 1.

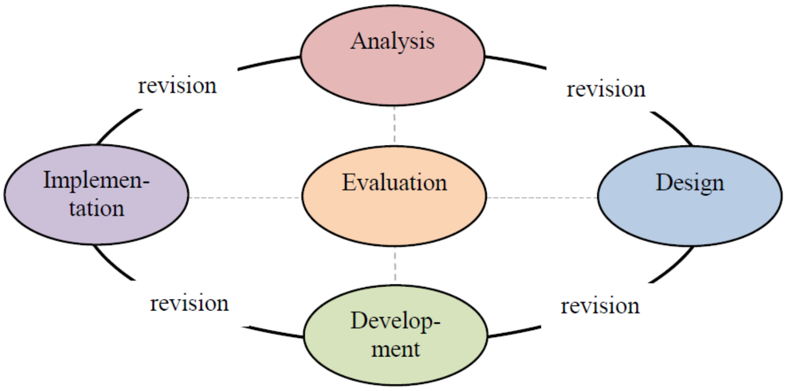


FIGURE 1. The ADDIE Approach for Developing Products in the Form of Learning Design

In the analysis phase, teacher interviews and classroom observations identified curriculum requirements and existing gaps in CK-12 usage. During the design phase, the product was developed by determining the format of the STEM-based practical module incorporating CK-12 simulations and outlining the key components of the module. In the development phase, the product was created, research instruments were designed, expert validation was conducted, and product trials were performed. In the final phase, implementation, the developed module was applied to the research subjects. Subsequently, questionnaires were administered, and learning assessments were given to the students.

The subjects of validation in this study are validators or experts, consisting of two lecturers from the Physics Education at the Faculty of Teacher Training and Education, University Sulawesi Barat, and one physics teacher from a Senior High School or its equivalent. Experts evaluated the module based on clarity, relevance, and alignment with STEM objectives. Several aspects of the validation assessment include appearance, language, presentation, and content. The trial and implementation phase subjects are the students and physics teachers of class X MIA at SMAN 1 Alu and the students and physics teachers of class X IPA at MAN 2 Polewali Mandar. In the limited trial, six students were selected as the research subjects, conducted at SMA Negeri 1 Alu. Then, in the broad trial, 15 students and 1 physics teacher were involved, conducted at MAN 2 Polewali Mandar. Finally, in the implementation phase, 1 class of students and one physics teacher were selected, and the implementation was performed again at SMAN 1 Alu. Although the limited trial included only six students, the subsequent more exhaustive trial and implementation phase increased the sample size to ensure more robust results. In general, the procedure in this study can be seen in FIGURE 2.

The research instrument is a measuring tool, and the researcher uses tests, questionnaires, interview guidelines, and observation guidelines to collect data in a study (Sugiyono, 2022). A learning device is considered feasible if it meets three criteria: valid, practical, and effective (Santi & Santosa, 2016). Therefore, the instruments used in this study are presented in TABLE 1.

TABLE 1. The Research Instrument

No.	Criteria	Data	Data Source	Research Instrument
1.	Valid	Expert Validation Results	Expert	Expert Validation Questionnaire
2.	Practical	Student Responses	Student	Student Responses Questionnaire
3.	Effective	Learning Outcomes	Student	Learning Outcomes Test

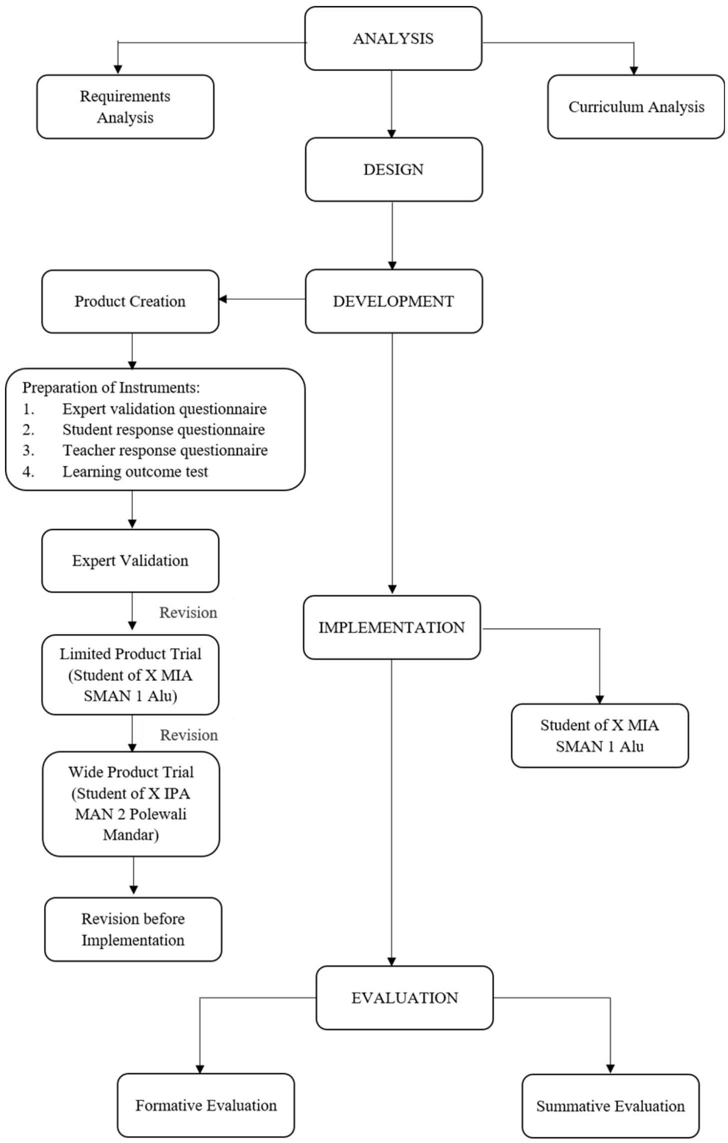


FIGURE 2. Framework

To determine whether the developed product meets the validity criteria, EQUATION 1 below is used.

$$Valid = \frac{\sum assessor's\ per-item\ score}{\sum maximum\ score} \times 100\% \tag{1}$$

To assess the practicality of the developed product, EQUATION 2 below uses a student and teacher response questionnaire.

$$Practical = \frac{\sum user\ per-item\ score}{\sum maximum\ score} \times 100\% \tag{2}$$

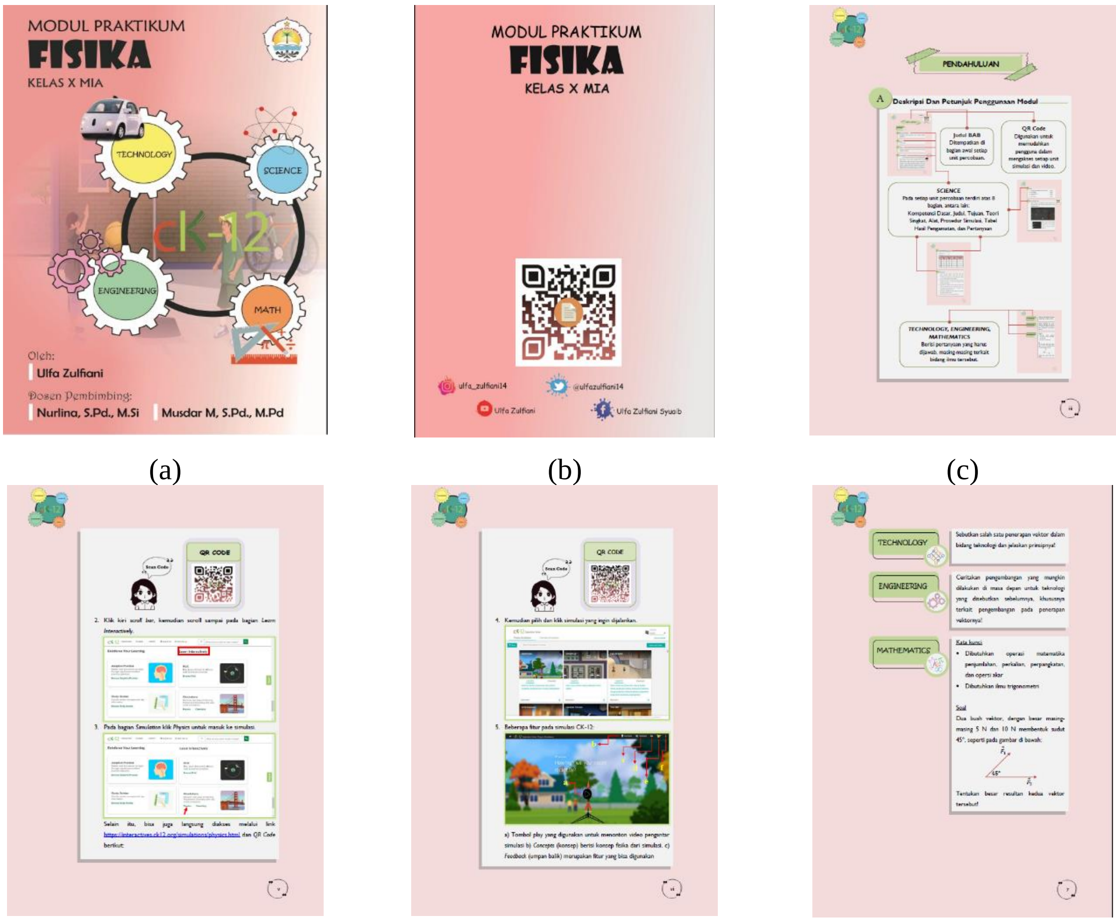
The product is effective if students achieve learning outcomes that meet the KKM (Minimum Completeness Criteria). EQUATION 3 below evaluates the effectiveness of the developed product.

$$Effective = \frac{\sum student\ who\ have\ completed}{\sum all\ students} \times 100\% \tag{3}$$

RESULTS AND DISCUSSION

In this study, a practical device in the form of a practical module was developed, accompanied by the preparation of lesson plans (RPP) and learning outcome tests, which serve as supporting tools for implementing or using the module. The focus of the development remained on the practical module itself, so the outcome of this study is a physics practical device in the form of a STEM-based CK-12 simulation-assisted practical module for grade X MIA students.

The first phase of this study is the analysis phase. This phase is conducted to determine what product needs to be developed and what the development of that product should look like. The analysis phase includes needs analysis and curriculum analysis. After the analysis phase, the next step is the design phase. In this phase, the format and key components of the practical module to be developed are determined by reviewing several previously existing practical modules. Following this, the development phase is carried out. In this phase, the product is created and tested. An example of the product that has been developed can be seen in FIGURE 3.



(a) (b) (c)

(d) (e) (f)

FIGURE 3. STEM-based Physics Modules with CK-12 Simulations for High School: (a) Front Cover, (b) Back Cover, (c) (d) (e) (f) Content with STEM-based Approach

Validity

This study's validators are two physics education lecturers and one teacher. The results of the practical module validation from the three validators are presented in a bar chart in FIGURE 4. Based on FIGURE 4, the average assessment of the three validators for all aspects of the practical module validation sheet is 87.78%. These validation results indicate that the practical module meets the criteria of being highly valid.

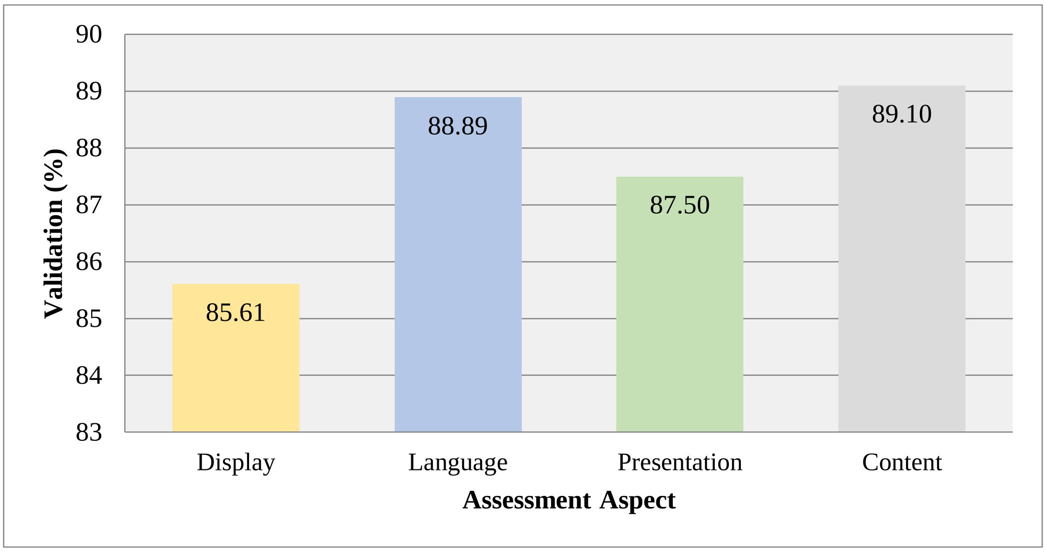


FIGURE 4. The Result of Validators for Practical Modul

The practicality of the practical module is assessed based on the results of the student response questionnaire and the teacher response questionnaire. The limited trial was conducted at SMA Negeri 1 Alu in class X MIA 2, with a total of 6 student participants. In this trial, a student response questionnaire was used to assess students' responses to the practical module before conducting a wider trial. The results of the student responses for each assessment aspect in the student response questionnaire are presented in a bar chart in Figure 5. Based on Figure 5, the average assessment of the 6 students from class X MIA 2 SMA Negeri 1 Alu for all aspects of the student response questionnaire is 93.57%. Therefore, based on Table 3, the CK-12 simulation-assisted STEM-based practical module in the limited trial meets the criteria of being highly practical.

After a limited trial, a more exhaustive trial was conducted at MAN 2 Polewali Mandar, in class X IPA 1, with 15 student subjects and 1 class X IPA physics teacher. In this trial, student and teacher response questionnaires were used to assess the student's and teacher's responses to the practicum module before it was used in the implementation phase. The results of the students' responses for each assessment aspect in the student response questionnaire are presented in a bar chart in Figure 6. Based on FIGURE 6, the average assessment score of the 15 students from class X IPA 1 at MAN 2 Polewali Mandar for all aspects of the student response questionnaire is 88.96%. These results indicate that the STEM-based CK-12 simulation-assisted practicum module in the broad trial, according to the student's responses, falls into the very practical category.

The results of the teacher's responses for each assessment aspect in the teacher response questionnaire are presented in a bar chart in Figure 7. Based on FIGURE 7, the average assessment score from the physics teacher of class X IPA at MAN 2 Polewali Mandar for all aspects of the teacher response questionnaire is 85.00%. This indicates that the STEM-based CK-12 simulation-assisted practicum module in the broad trial, based on the teacher's response, falls into the very practical category.

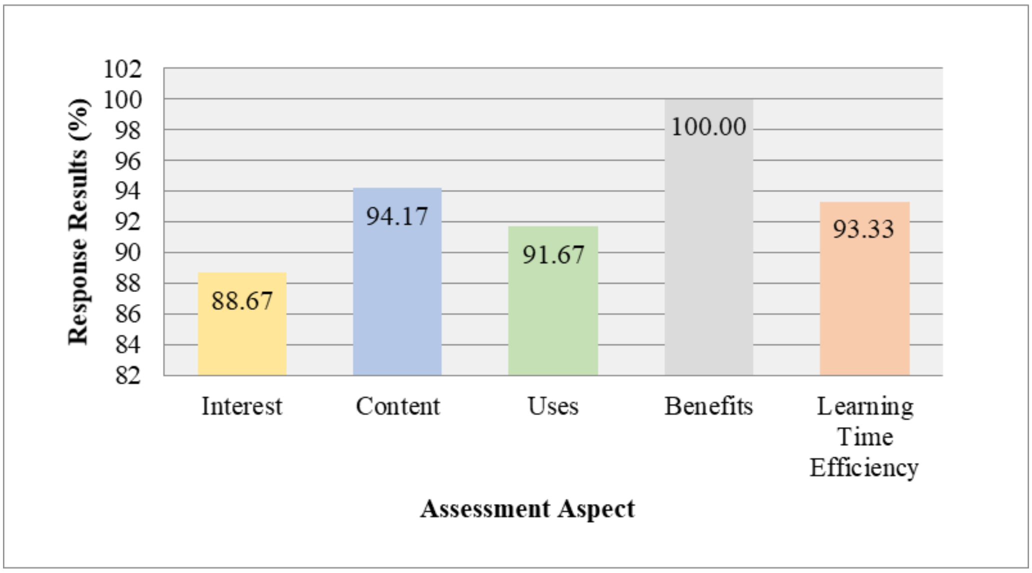


FIGURE 5. Student Response Results in Limited Trial

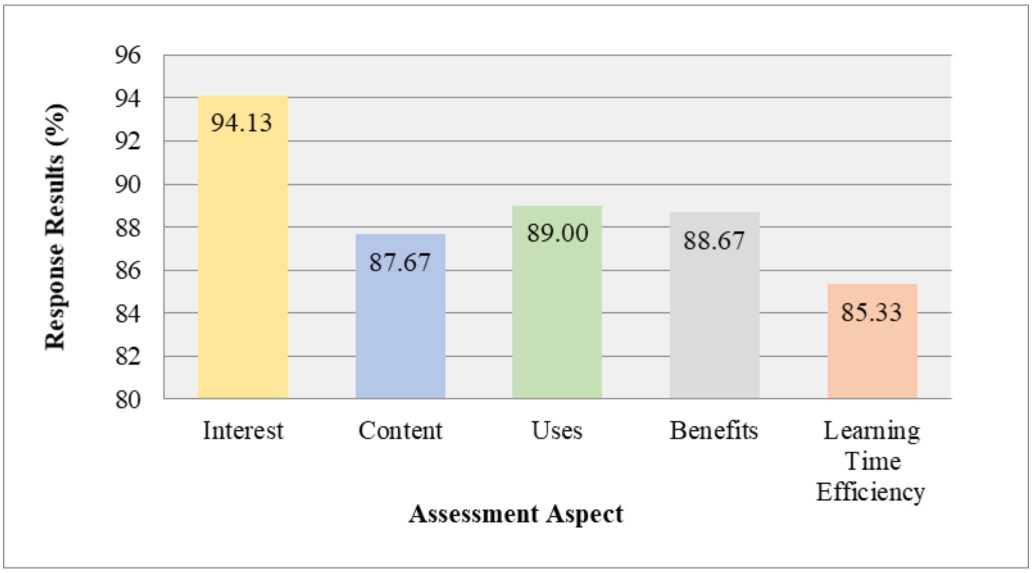


FIGURE 6. Student Response Results in the Wide Trial

After conducting the broad trial, the next phase was the implementation stage, which took place at SMA Negeri 1 Alu, with the research subjects being all the students in class X MIA 1 and 1 physics teacher of class X MIA. In this phase, student and teacher response questionnaires were also used to assess student and teacher responses to the practicum module. The results of the students' responses for each assessment aspect in the student response questionnaire are presented in a bar chart in Figure 8. Based on FIGURE 8, the average assessment score of 21 students from class X MIA 1 at SMA Negeri 1 Alu for all aspects of the student response questionnaire is 90.29%. This indicates that the STEM-based CK-12 simulation-assisted practicum module in this implementation phase, based on the students' responses, falls into the very practical category.

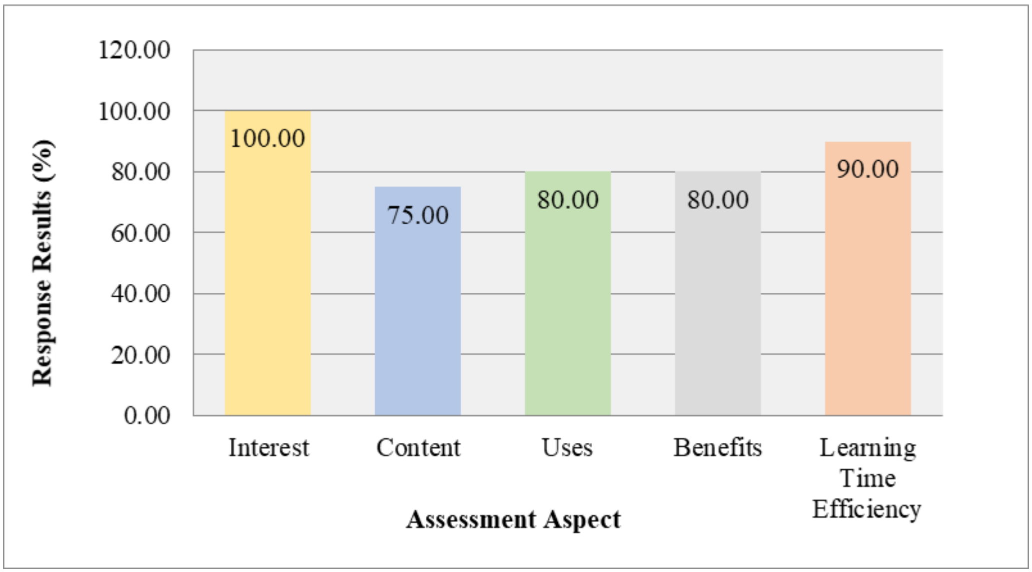


FIGURE 7. Teacher Response Results in Wide Trial

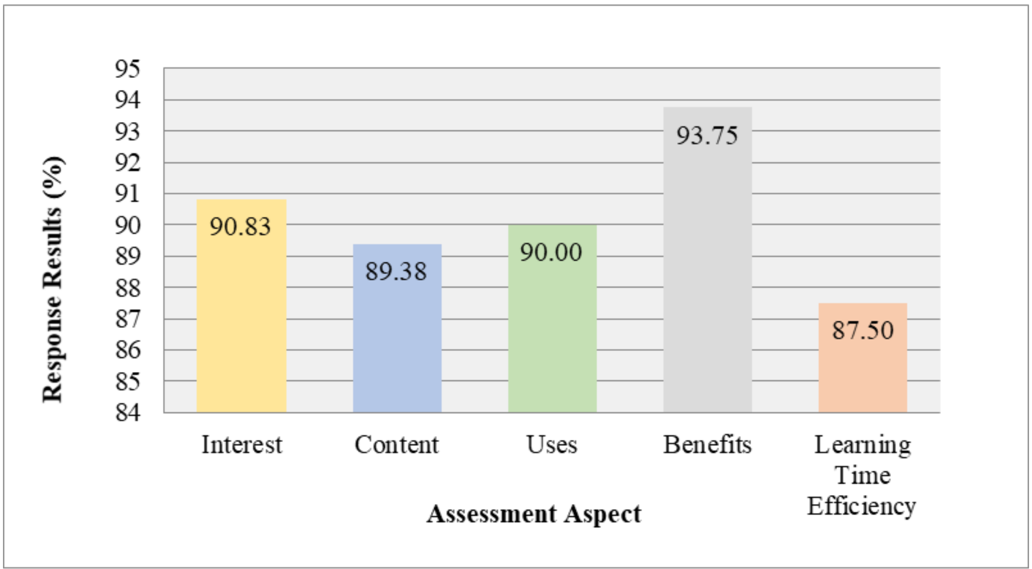


FIGURE 8. Student Response Results in Implementation Stage

The results of the teacher responses for each assessment aspect on the teacher response questionnaire are presented through a bar chart in FIGURE 9. Based on FIGURE 9, the average assessment from the SMA Negeri 1 Alu physics teachers for all aspects of the teacher response questionnaire is 99.00%. This indicates that the STEM-based CK-12 simulation-assisted practical module in this implementation phase, based on teacher responses, falls into the very practical category.

Effectiveness

The effectiveness of the practicum module can be seen from the students' learning outcomes during the implementation phase. Before being used, the learning test results were first validated by three validators who validated the product and the response questionnaire. The validation results from the three validators showed that out of the 30 questions created, one question had moderate validity, while the others had high validity. The question with moderate validity was removed from the list along with 4 other questions, so the total number of questions used was 25. The number of students who took the test was 24. The results of the test showed that 19 students passed and five students did not pass. These data were then analyzed, yielding a percentage of 79.17%. This aligns with Sari's (2021) findings, which demonstrate that developing practical modules based on the STEM approach can enhance students' independence in performing practical tasks (Sari, 2021). Therefore, based on the statement by Putri (2020), if the learning outcome percentage reaches 70% - 79%, it can be said that the developed product has met the effectiveness criteria.

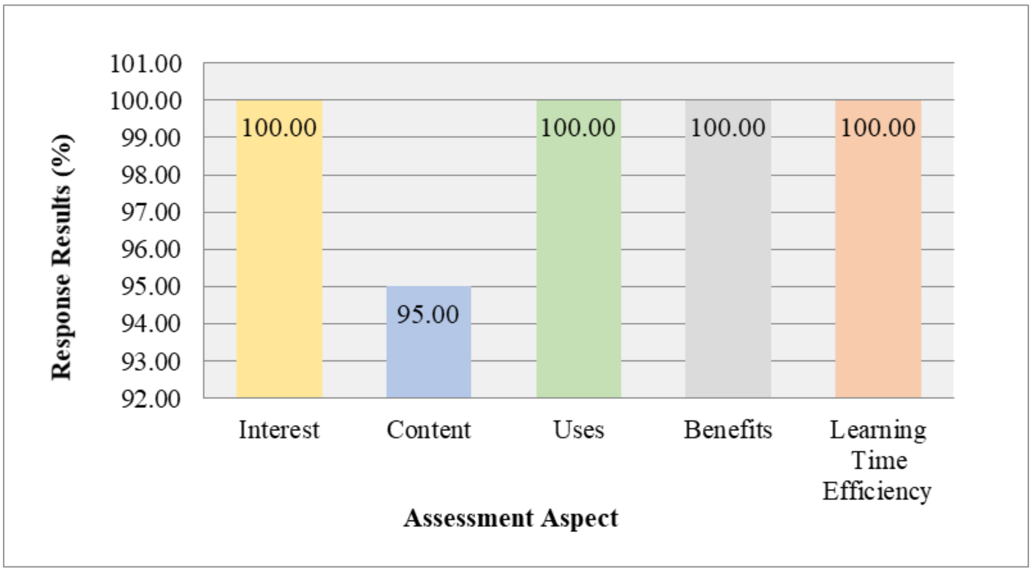


FIGURE 9. Teacher Response Results in the Implementation Stage

CK-12 has designed new physics simulations to bridge abstract concepts with the real world, helping students learn key concepts by relating them to real-world examples around them. Each simulation aids in explaining various concepts in an engaging and relevant way that students can understand and enjoy. While the current simulations explore physics concepts, future simulations will cover other STEM topics.

Based on the research that has been conducted, the researcher proposes several recommendations, namely: (1) for students, it is expected that with the existence of this practical module, they will become more enthusiastic about learning physics, as this module allows physics learning to go beyond just studying theory; (2) for teachers, it is hoped that with this practical module, they will regularly conduct physics lessons through practical work after students have studied the theory; (3) for schools, it is expected that this practical module will encourage a deeper study of the CK-12 simulation, as it offers many other subjects and features that can be used to innovate teaching methods in schools; (4) for other researchers, it is hoped that they will be able to develop practical physics modules with the assistance of the CK-12 simulation for other topics and further explore the STEM approach content in practical modules. Additionally, for the selection of topics, it is unnecessary to cover many; if possible, it is sufficient to focus on specific topics with several experiments. Future research involving a broader group of students should be conducted on a larger scale. Implementing large-scale trials in this study was not feasible due to the limited number of respondents and potential biases in teacher evaluations. These factors may influence the feedback provided by teachers from a single school, thereby limiting the generalizability of the findings.

CONCLUSION

Based on the research results obtained, it can be concluded that (1) the STEM-based CK-12 simulation-assisted physics practical module for class X MIA that was developed has met the very valid criteria with a percentage of 87.78%; (2) the STEM-based CK-12 simulation-assisted physics practical module for class X MIA that was developed has met the very practical criteria based on the responses from students and teachers, with percentages of 90.29% and 99.00%, respectively; (3) the

STEM-based CK-12 simulation-assisted physics practical module for class X MIA that was developed has met the effective criteria with a percentage of 79.17%. The findings indicate that STEM-based physics modules integrated with CK-12 simulations can substantially improve the quality of physics teaching and learning at the high school level. Furthermore, future studies should investigate their application to other topics. Future studies should involve a larger sample size and a more diverse group of students. Implementing large-scale trials in this study was impossible due to the small number of respondents and the potential biases in teacher evaluations. These limitations may affect the feedback from teachers at a single school, thus restricting the generalizability of the results.

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