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Physics electronic teaching material-integrated STEM education to promote 21st-century skills

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Abstract

There is widespread agreement that 21st-century skills are skills that should be possessed by students in the current era; however, generally, the component value of these skills is low. This research aims to investigate the effectiveness of the physics electronic teaching material-integrated STEM education (PETMS) in improving the 21st-century skills of students. This research was an experimental study with a post-test-only design with a non-equivalent group. The research subjects consisted of 66 students in two groups. The results indicated that the use of the PETMS was effective in improving students' mastery of concepts and three aspects of 21st-century skills: creative thinking, critical thinking, and communication. Based on this result, it is inferred that the PETMS is an effective teaching material in promoting students' 21st-century skills and is expected to be a relevant reference to enhance the quality of physics learning and to apply in the 21st-century learning era.

Keywords: Teaching material, STEM education, critical thinking, creative thinking, communication.

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1. Introduction

Currently, education has been dragged into the flow of the knowledge society as effect of the disruption of the ICT, social, and economic globalisation (Voogt & Roblin, 2012). This relentless evolution of technology impacts a society whose jobs can be replaced by technology (Schwab, 2016). Certainly, our society should also be able to become a knowledge society by possessing the competencies required for this trend so that they could continue to be productive (Voogt & Erstad, 2018). This triggers the change in the educational paradigm to shift to the development of these competencies because these competencies do not simply appear, they are developed. The 'old' education which only relies on information from the teacher fully in transferring knowledge is exceptionally not relevant more. Therefore, the current education system should guarantee these 'new' literacies and competencies and this will also be in line with the emergence of 'new' ways of learning (Tan et al., 2017).

Based on preliminary studies, integrating STEM in teaching material of senior high schools in Padang City was suboptimal at 48%. Teaching material had not been digitised. The 21st-century skills level and student learning outcomes also indicated suboptimal development. The average of each of the 21st-century skills' indicators of students was still relatively weak and the percentage of students' 21st-century skills level as a whole was 61.33%. Then, the level of completeness of student learning in the three schools was less than 60%. The research of Siddiq et al. (2017) reported that the development of students' 21st-century skills highly requires the attempts of teachers and researchers through the development of relevant learning components, such as the development of electronic teaching material, learning media or virtual lab simulations. According to Batoon et al. (2018), electronic teaching material consists of components of learning that highly affect students' 21st-century skills.

These matters indicate that physics teaching materials that support technology-based teaching and scientific practice are relevant solutions to be applied currently. In this study, an investigation was carried out on the effectiveness of physics electronic teaching material-integrated STEM education (PETMS) in improving students' mastery of concepts and three aspects of 21st-century skills: creative thinking, critical thinking and communication. The results of this research can be used as a reference for educators in the field of physics and other science fields in providing a better learning experience for students in obtaining competencies according to the needs of the current era. Furthermore, PETMS is expected to contribute to carrying out learning activities in schools better and fluently while achieving 21st-century learning goals.

1.1. Conceptual framework

1.1.1. The 21st-century skills

These 'new' literacies and competencies are 21st-century skills that are widely agreed upon as competency standards that students need to possess to fulfil the demands of success in their future work and life (Ball et al., 2016; Partnership for 21st Century, 2019). These skills have also been recognised as the main cognitive competencies in the 21st century. This basic category illustrates that these skills include 4C skills, literacy skills, and life skills (Stehle et al., 2019; Laar et al., 2020; Rahim et al., 2021; Festiyed et al., 2022). In other words, these skills are integrated. To realise its development in the classroom, the indicators of 4C skills (communication, collaboration, critical thinking and creative thinking) should be regarded from the digital aspect (van Laar et al., 2017, 2020), and consequently, the three basic categories of 21st-century skills can be accommodated (Novitra et al., 2021).

Creative thinking is defined as the ability to think and work with others to generate and implement new ideas that demonstrate originality. Critical thinking is defined as the ability to use thinking, which includes the ability to use reasoning (inductive or deductive), and the ability to analyse, synthesise and reflect on information. Communication is defined as the ability to effectively articulate thoughts orally, in writing and non-verbally in various situations. Collaboration is defined as the ability to work effectively with other people in a group to achieve a goal (Partnership for 21st Century, 2019).

1.1.2. E-teaching material

The 'new' way of learning in physics learning is learning that has a base of technology-based teaching and scientific practice that is combined in a balance or referred to as a high-tech and high-touch learning approach (Novitra et al., 2021). However, the aspect that researchers and educators often pay less attention to in developing 21st-century skills for students is the influence of teaching material. Besides the influence of learning strategies that regulate students' scientific processes, teaching material that is in accordance with the curriculum and current issues create effective learning in the classroom to achieve learning objectives. This can be realised if the teacher develops teaching material with systematic, unique, interesting and relevant material in the 21st-century era. For this reason, the teaching material used in the learning should be able to support this paradigm, such as digitising teaching material in electronic form. Electronic teaching material is the appropriate learning resource for the character of today's students as digital natives (Chen & Su, 2019; Laksana et al., 2019).

Electronic teaching material is generally in PDF, plucker, HTML, epub or Mobi formats, e-book and mobile devices in education (Fojtik, 2015). Electronic teaching material is a learning resource able to be displayed as writing, pictures, simulations, quizzes and interactive multimedia (Kozminsky & Asher-sadon, 2013; Suwatra et al., 2018). Electronic teaching material is easier to develop in a more interesting form than ordinary teaching material, thus teachers have more opportunities to build learning more interesting (Klement & Marešová, 2014). In addition, electronic teaching material also has an impact on improving students' ICT skills (Bates et al., 2016), independence in learning (Ogata et al., 2015) and interests and learning experiences (Adam & Suprapto, 2019).

Based on these 21st-century learning trends, the direction of learning objectives in general currently is the development of interdisciplinary thinking. Likewise, the main goal of learning physics currently is not simply to the development of physics knowledge but should be able to develop interdisciplinary thinking also. In other words, technology-based teaching and scientific practice should be applied in an attempt to develop interdisciplinary thinking, namely 21st-century skills. One form of learning that is in line with this goal is STEM education (Mater et al., 2020; Sivaraj et al., 2020).

1.1.3. STEM education

STEM (science, technology, engineering, and mathematics) is a form of learning curriculum capable of promoting students in higher order thinking and innovative thinking habits in facing global challenges (Vennix et al., 2018). STEM education is a symbol of the relationship between the four fields of science, namely science, technology, engineering and mathematics (Basham & Marino, 2015; Stohlmann, 2019), to enhance the development of the latest innovative technology (Shukshina et al., 2021). STEM is defined as a comprehensive approach to education that combines various disciplines into a learning paradigm. This approach is actualised with design-based learning strategies, inquiry discovery and problem-solving (Falloon et al., 2020).

STEM is built to prepare students to have a set of skills that they can use in various aspects of their lives, such as thinking, reasoning, collaboration, scientific and creativity skills (English, 2016). Moreover, Mater et al. (2020) stated a serious effort in developing skills such as 4C skills. In addition, STEM accommodates students' scientific activities such as asking questions, investigating problems based on real-world contexts and finding problem-solving solutions. This means that STEM makes them productive students. STEM education is capable of changing students' mindsets and perspectives on technology and related fields of science (Ellis et al., 2020). Therefore, the application of STEM in schools is highly important, in both developing students' 21st-century skills and fulfilling the requirement of the current learning trends.

1.2. Related research

Research on electronic teaching materials has been carried out by several previous researchers. Sinaga et al. (2022) examined the effect of interactive electronic teaching materials on students' critical thinking skills. From the data analysis, it can be stated that the thinking skills of the experimental group students are higher than the control group. Teknowijoyo et al. (2022) stated that digital teaching materials are effective for improving students' critical skills. Pursitasari et al. (2022) found that interactive teaching material was feasible to support students' critical thinking skills. On the other hand, Hikmawati et al. (2020) concluded that digital teaching materials on the earthquake theme can improve students' STEM literacy.

Another study investigated the effect of teaching materials in the form of e-modules on students' thinking skills. Safitri et al. (2021) concluded that e-modules with Kvisoft Flipbook Maker can improve students' thinking skills. From the research results of Suwatra et al. (2018), it can be concluded that the e-module for global warming can improve students' critical thinking skills. This study is intended to complement previous research by integrating STEM education into electronic teaching materials and investigating its effects on knowledge and skills aspects including critical thinking, creative thinking and communication skills.

1.3. Purpose of the study

In this study, an investigation was carried out on the effectiveness of the PETMS in improving students' mastery of concepts and three aspects of 4C skills: critical thinking, creative thinking and communication. The effectiveness of this PETMS is expected to be a reference in an attempt to improve the quality of physics learning, especially in an attempt to provide learning experiences that are in accordance with the current era. Furthermore, PETMS is expected to contribute to carrying out learning activities in schools better and fluently while achieving 21st-century learning goals.

2. Method and materials

2.1. Research model

This research can be categorised as a quasi-experimental type of research. The post-test-only design with the non-equivalent group was used to analyse the effect of PETMS. The experimental group used PETMS, while the control group used publisher textbooks. The experimental group and the control group had the same initial ability before using this teaching material. PETMS has been validated by five experts. The average value of the validity of PETMS is 88 and this value can be categorised as high. Revision of PETMS was carried out based on input from experts. The display of PETMS after being revised is shown in Figure 1.

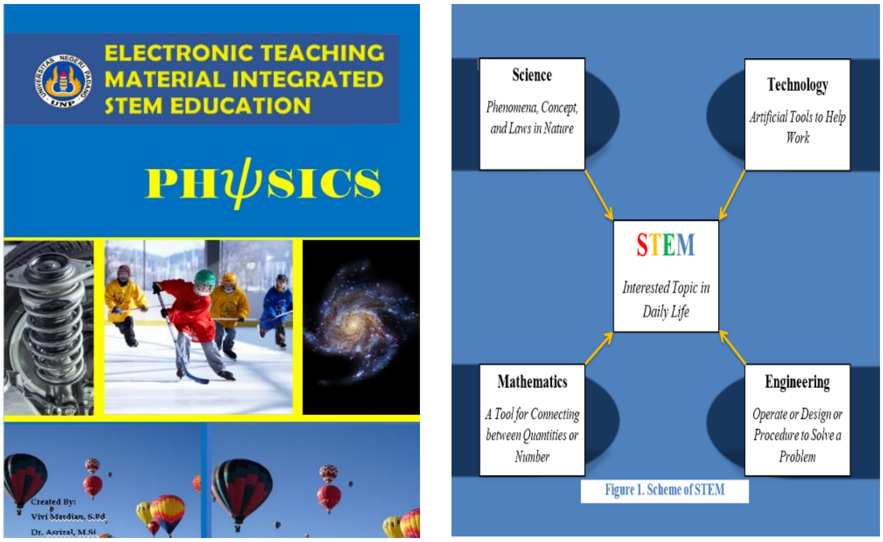

Figure 1. Representative screenshots from PETMS

Implementation of PETMS is accommodated by the online-based inquiry learning model. This learning model consists of five phases, such as online orientation, problem identification in e-resources, exploration using ICT tools, report findings and closure (Novitra et al., 2021). In the treatment stage, the PETMS is implemented in learning activities. Then, PETMS was applied for five meetings. The results of the assessment at the last meeting were used as the results of the post-test.

2.2. Participants

The population comprised 241 11th-grade students majoring in science. The sample was selected using a purposive sampling technique, namely by considering representative data (normal distribution and homogeneous learning outcomes) (Masyhud, 2016). The samples obtained were 66 students from 2 different classes with the same initial ability in the experimental group and the control group.

2.3. Data collection tool

There are two instruments to collect research data, namely a written test and a performance assessment sheet. The instrument to assess the knowledge aspect is a written test with multiple choices. On the other hand, the instrument for assessing 21st-century skills, including critical thinking, creative thinking and communication skills, is the performance assessment sheet. The indicators on the instrument refer to Greenstein (2012) and Moma (2017) (creative thinking), Facione and Gittens (2013) (critical thinking) and Handayani and Suliswora (2021) (communication). Indicators of thinking skills in the performance assessment sheet include interpretation, analysis, evaluation, inference and explanation. Indicators of creative thinking skills consist of fluency, flexibility of thinking, originality and assessment. Meanwhile, indicators of communication skills include investigating information, listening and observing, scientific writing, presenting knowledge and presenting information.

2.4. Data collection process

Knowledge aspect data was obtained from the post-test result after applying PETMS. The question grids for the test questions were arranged based on indicators to achieve ability in the elasticity material. The test questions were carried out in a class from a different school. The test result was analysed to get questions with good criteria including the index of difficulty and discriminating power.

The test results that met the criteria were used for post-test questions. After applying PETMS to the experimental group, the post-test question was given to the experimental group and the control group.

Data on critical thinking skills, creative thinking and communication were obtained during the learning process. The assignments were designed to measure all three 21st-century skills of students. Students were asked to do assignments related to an interesting topic in everyday life. This topic integrates the components of STEM education. Students' performance was assessed based on the assignments that have been submitted to students. Through the performance assessment sheet, data were obtained from the three 21st-century skills of students.

2.5. Data analysis

Data on aspects of knowledge and skills of the 21st century were analysed by descriptive statistics and include the form of measures of central tendency and dispersion, tables and diagrams. The normality of the knowledge and skills data in each experimental group and control group was tested with the Lilliefors test. Student's *t*-test was used to test the hypothesis for data having a normal distribution and a homogeneous variance. Based on the description of the data collection instrument, there are two indicators to define that the PETMS is effective. First, there are differences in the levels of critical thinking, creative thinking, and communication between the experimental group and the control group. Second, the average score of the experimental group's cognitive competence reached a score of 75, and 70% of students scored ≥65.

3. Results

3.1. effectiveness of PETMS on knowledge aspect

PETMS was implemented in learning for five meetings. After implementation, the test of learning outcomes in the aspect of knowledge was given to both groups of students. The results of this test can be seen in Table 1. The results of the effectiveness of the PETMS indicate that the electronic teaching material is better at achieving student learning outcomes in the knowledge aspect than the publisher textbook.

Table 1. Statistical Parameter Analysis of Knowledge Aspect

Statistical Parameter	Experimental Group	Control Group
N	33	33
Average	77	70
Standard Deviation	10.28	11.90
Variance	105.72	142.00
Lowest Score	57	43
Highest Score	97	90
Normality Test (L_0)	0.11	0.14
Homogeneity Test	F=1.77	
t-test	t_{value}=2.55	

The data for both groups were normally distributed ($L_0 < L_{table}$) and homogeneous ($F_{value} < F_{table}$). Based on the data in Table 1, the average value of students on the knowledge aspect in online physics learning using PETMS is higher than students who do not use it. The result of the t-test indicates that the implementation of PETMS in online physics learning has a significant effect on aspects of students' knowledge ability ($t_{value} > t_{table}$ = 2.55 > 1.99). The results indicate that the use of PETMS on elasticity material in physics learning is effective in improving students' knowledge. Integrating STEM contexts into the digital world appears more relevant currently and constructs students' knowledge of concepts and skills more comprehensively. These STEM practices and digital interactions enable students to engage with technology tools, devices and practices in social contexts that are appropriate to current trends. This emphasis on learning practices in this way assists teachers in forming STEM as an integral part of students' daily life experiences for solving real-world problems (Sivaraj et al., 2020). Consequently, PETMS provides learning with a more relevant, comprehensive experience and assists students in mastering learning content more deeply. In addition, the PETMS also provides more motivation to students in learning activities. This is due to the electronic teaching material containing elements of interactive learning media (Lim et al., 2020), and capability to improve students' reading skills and reduce misconceptions (Tsuei et al., 2020).

3.2. Effectiveness of PETMS on creative thinking

Creative thinking skills assessed in this study consist of five components, such as fluency of ideas (FI), flexible thinking (FT), originality (OR), elaboration (EL) and assessment (AS). The results of the data plot of the components of students' creative thinking skills are shown in Figure 2. The data in Figure 2 indicate that there is an average difference in each component of students' creative thinking between the two sample groups.

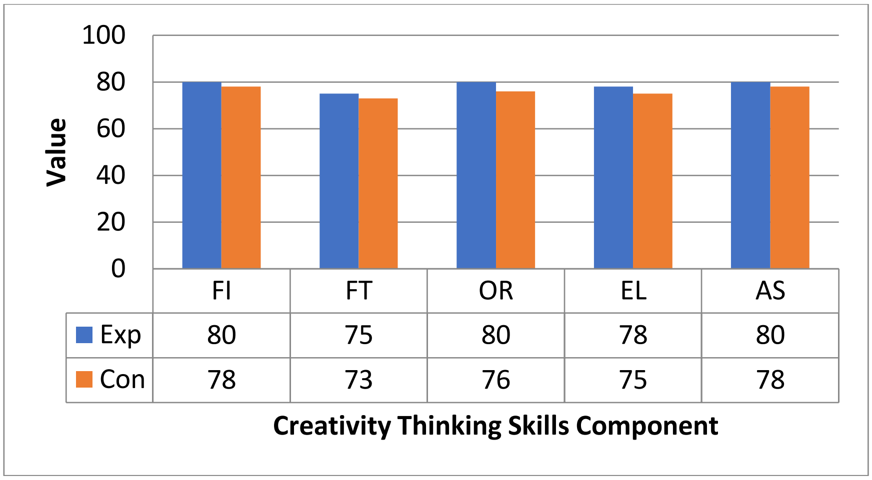

Figure 2. Creative Thinking Skills Analysis Results

Table 2. Statistical Parameters Analysis on the Aspect of Creative Thinking Skills

Statistical Parameter	Experimental Group	Control Group
N	33	33
Average	79	76
Standard Deviation	2.91	3.68
Variance	8.45	13.42
Lowest Score	73	71
Highest Score	84	81
Normality Test (L_0)	0.10	0.10
Homogeneity Test	F=1.75	
t-test	t_{value} =3.67	

The data for both groups were normally distributed ($L_0 < L_{table}$) and homogeneous ($F_{value} < F_{table}$). From the result of data analysis in Table 2, it can be stated that the t_{value} is outside the area of acceptance of the null hypothesis. The result of the hypothesis test indicates that there is a significant difference in creative thinking skills between the two sample groups. This result can reveal that PETMS has a significant effect on students' creative thinking skills. Thus, the implementation of PETMS in physics learning is effective to promote creative thinking of students.

The results of the five components of creative thinking skills in the experimental group were better than the control group. This is due to the electronic teaching material capable of developing students' creative thinking skills, including fluency, originality, flexibility, elaboration and assessment (Adawiyah et al., 2019). Electronic teaching material that has audio and visual learning resources encourages students to be promoted in providing various opinions. The menus available in electronic teaching material such as bio-mini-lab and bio-ma promote students' creative thinking skills in conducting group discussions, finding concepts, applying concepts and conducting evaluations (Hikmaturrosyidah & Rachmadiarti, 2022). In addition, the mind-mapping learning strategy contained in the electronic teaching material also promotes students' creative thinking skills in problem-solving and generating ideas (Cahyanti et al., 2021). Students are provided with the discretion to present hypotheses to the problems. Then, in the data collection stage, electronic teaching material plays a big role as a source of information for students in solving the problems posed.

Likewise, the STEM content in this electronic teaching material also encourages the improvement of students' creative thinking skills. According to Struyf et al. (2019), integrating STEM with the practice of inquiry, problem-solving and collaborative learning improves students' creative thinking because it emphasises student involvement in asking questions, experiential learning and the activities that enable them to discover new concepts and develop new understandings. As a result, students are accustomed to using their various imaginations and there is an improvement in creative thinking in every learning that is held (Chen & Chen, 2021).

3.3. Effectiveness of PETMS on critical thinking

Critical thinking skills assessed in this study consist of five components. These components include interpretation (IT), analysis (AN), evaluation (EV), inference (IF) and expansion (EK). The results of the data plot of the components of students' critical thinking skills are shown in Figure 3.

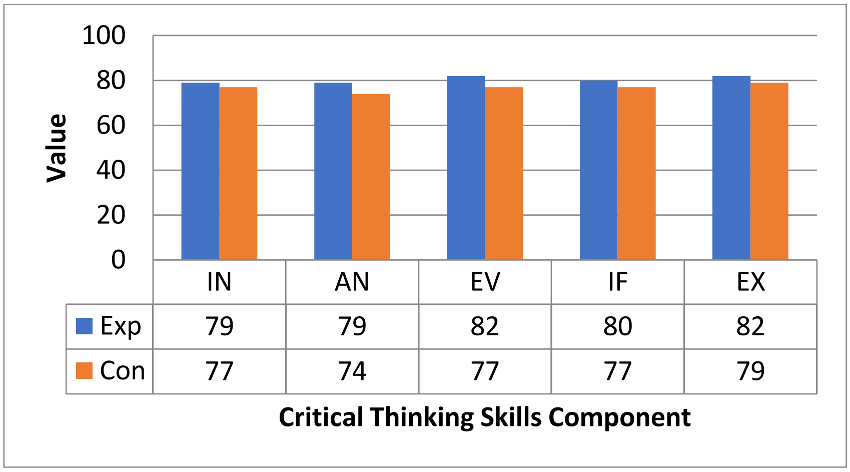

Figure 3. Results of Analysis of Students' Critical Thinking Skills

Table 3. Statistical Parameters Analysis of Critical Thinking Skills

Statistical Parameter	Experimental Group	Control Group
N	33	33
Average	80	77
Standard Deviation	3,65	2,93
Variance	13,00	8,59
Lowest Score	75	69
Highest Score	86	80
Normality Test (L_0)	0.14	0.15
Homogeneity Test	F=1.44	
t-test	t_{value} =3.67	

The data for both groups were normally distributed ($L_0 < L_{table}$) and homogeneous ($F_{value} < F_{table}$). For this reason, the t-test was applied to test the hypothesis. From the data analysis, the t_{value} is 3.67. This t_{value} is outside the area of acceptance of the null hypothesis. The results of the t-test state that there is a difference in critical thinking between students who use PETMS in online learning and students who do not use it. It means that the implementation of PETMS in online physics learning has a significant influence on the critical thinking of students. Thus, the implementation of PETMS in online physics learning is effective to promote the critical thinking skills of students.

The results of the five components of critical thinking skills assessment of students who use PETMS were better than students who do not use it. In addition to the capability of developing students' critical thinking on each indicator, the implementation of interactive teaching material in learning is capable of constructing students' critical thinking skills on each of the indicators (Suyatna et al., 2018). The problems presented in the interactive teaching material encourage students to analyse facts and data according to the concepts they have learned. According to Ambarwti et al. (2019), the interactive teaching material that possesses a scientific process is effectively used by students to increase learning independence and students' critical thinking skills. The electronic teaching material support students in learning in the classroom and at home with an attractive display and media that will reduce student boredom in learning and have a significant influence on students' critical thinking skills (Seruni et al., 2020).

In addition, the STEM content in the electronic teaching material also influences the results obtained. This is in line with previous research which has proven that STEM is relevant to apply in developing students' critical thinking skills (Hacioğlu & Gülhan, 2021; Mater et al., 2020). These results are also related to the fact that the process of generating problem solutions in a STEM context affects the development of students' critical thinking skills (Mater et al., 2020; Rizaldi et al., 2020; Savran Gencer & Dogan, 2020; Sumarni & Kadarwati, 2020). STEM accommodates student activities to be more active in groups to solve a problem by evaluating all the ideas obtained and making decisions to solve the problem (Hacioğlu & Gülhan, 2021). In other words, PETMS assists students to build their own knowledge by encouraging them to be active in learning, identifying possible solutions, selecting data or information, giving opinions about the selected data and finally being able to provide possible problem-solving.

3.4. Effectiveness of PETMS on communication

Communication skills assessed in this study consist of five components, such as seeking information (SI), listening and observing (LO), scientific writing (SW), presenting knowledge (PK) and presenting information (PI). The results of the data plot of the components of students' communication skills are shown in Figure 4.

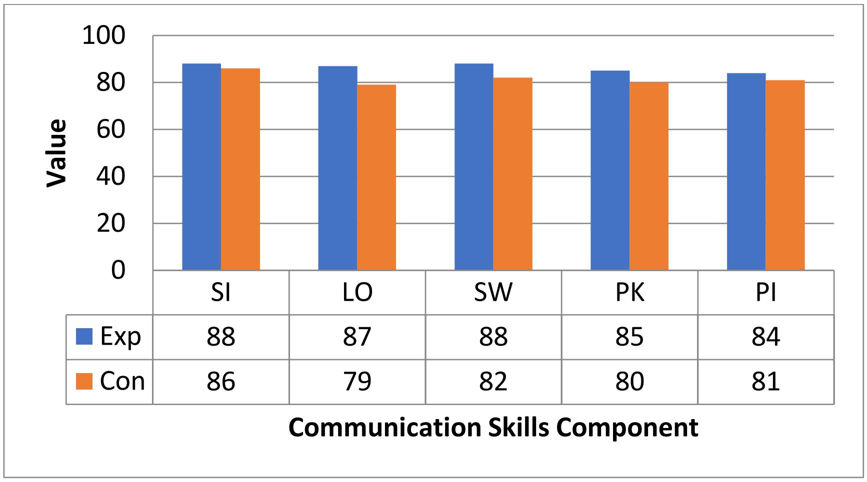

Figure 4. Results of the Analysis of the Aspect of Communication Skills

Table 4. Statistical Parameters Analysis of Communication Skills Data

Statistical Parameter	Experimental Group	Control Group
N	33	33
Average	86	82
Standard Deviation	4,00	3,50
Variance	16,00	12,29
Lowest Score	80	75
Highest Score	94	90
Normality Test (L_0)	0.08	0.011
Homogeneity Test	F=1.33	
t-test	t_{value} =5.43	

The data for both groups were normally distributed ($L_0 < L_{table}$) and homogeneous ($F_{value} < F_{table}$). The t-test was used to test the hypothesis based on the results of the normality test and this homogeneity test. The t_{value} of the hypothesis test is 5.43. This t_{value} is outside the area of acceptance of the null hypothesis. The result of this hypothesis test indicates that the value of the communication skills of students in online physics learning with PETMS is higher than the value of students who do not use it. This means that the implementation of PETMS in online physics learning has a significant effect on communication skills of students. Thus, the implementation of PETMS in online physics learning is effective to promote the communication skills of students.

4. Discussion

The results of the five components of critical thinking skills assessment in online physics learning using PETMS were better than in learning without using it. PETMS builds students' communication skills. The communication skills are oral and written communication. After experimenting according to the activities in the PETMS, students were asked to present the results of the experiment. The activities promote students' communication skills. According to Gistituati and Atikah (2022), the use of electronic teaching material that has a scientific process improves students' communication skills, such as making comparisons and explaining logical answers.

The use of virtual platforms in a STEM context improves the development of students' communication skills. Communication in a virtual environment improves students' communication levels due to reduced anxiety and higher self-efficacy (Owens & Hite, 2020). In line with the research of Wiharjo et al. (2020), students' communication skills are improved by using the 3D-Flip e-book in a virtual environment. Students' communication skills are also promoted by students' explanations of the experimental procedures that have been carried out. Therefore, the use of electronic teaching material assists students in developing communication skills with both in-person and portfolio assignments.

Based on the results obtained, the developed PETMS is effectively used in physics learning to improve students' 21st-century skills. The results of this study are in accordance with the results of Pane et al. (2021) and Asrizal et al.'s (2022) studies, which state that the development of electronic physics teaching material can improve students' higher order thinking skills. Interactive multimedia in electronic teaching material plays an important role in explaining abstract concepts in physics learning. All of these aspects indicate that the PETMS has the quality and is the appropriate solution in presenting pedagogical in accordance with the challenges of the 21st century, one of which is its capability to improve students' 21st-century skills and learning outcomes. Therefore, PETMS is relevant to be chosen in the current era in presenting electronic teaching material that has quality content, technical quality and pedagogical efficiency, and supports technology-based teaching and scientific practice.

Although the current PETMS appears to be effective, this research has some limitations. First, the sample size is not too large. To dig deeper into the effects of the PETMS, a large-scale experiment in future research is needed. Further research also needs to examine more deeply the effect of PETMS by controlling for other psychological factors, such as intelligence, motivation, perception, even gender and teacher competence factors.

5. Conclusion

The results of the study conclude that the PETMS is effective to promote student' learning outcomes in the knowledge aspect and three aspects of 21st-century skills, such as creative thinking, critical thinking and communication. There was a significant difference in students' creative thinking ($t_{value} > t_{table}$ = 2.55 > 1.99), critical thinking ($t_{value} > t_{table}$ = 3.67 > 1.99) and communication ($t_{value} > t_{table}$ (5.43 > 1.99) level between students in online physics learning with PETMS and students only in online physics learning. The average value of learning outcome in knowledge aspect in online physics learning with PETMS reached a score of 75 and 70% of students scored ≥65 and the implementation of online physics learning using PETMS has a significant effect on the knowledge aspect of students ($t_{value} > t_{table}$ = 2.55 > 1.99). Thus, this research contributes to the application of effective teaching material and is capable of assisting teachers in developing electronic teaching material in physics learning. In addition, other researchers can use this research as a basis for measuring the effect of electronic teaching material on a larger scale.

6. Recommendations

Two recommendations can be put forward based on the results of this study. Physics teachers can apply PETMS to promote aspects of knowledge and skills in the 21st century, especially creative thinking, critical thinking and communication skills. Students can use these electronic teaching materials to compose physics learning materials anytime and anywhere to create meaningful learning and develop 21st-century skills. Recommendations to other researchers based on the limitations of this study are to develop PETMS in other physical materials and other fields of science and consider other psychological aspects in testing its effectiveness.

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