STEM-Smart Physics E-Module to Promote Conceptual Understanding and 4C Skills of Students

Asrizal[1,*], Naurah Nazifah[1], Hansi Effendi[2], and Helma[1]

[1]Mathematics and Science Faculty, Universitas Negeri Padang, Indonesia
[2]Engineering Faculty, Universitas Negeri Padang. Indonesia
Email: asrizal@fmipa.unp.ac.id (A.); naurahnazifah13@gmail.com (N.N.); hans_79@ft.unp.ac.id (H.E.); helma_mat@fmipa.unp.ac.id (H.)
*Corresponding author

Manuscript received May 18, 2023; revised June 13, 2023; accepted September 20, 2023; published February 18, 2024

***Abstract*—The application of communication information in 21st-century learning has become popular to promote various students' skills. This study investigates the impact of the STEM-integrated smartphone-based physics E-module (STEM-Smart Physics E-Module) to promote students' conceptual understanding and Communication, Collaboration, Critical Thinking, and Creativity (4C) skills. This research method can be classified into a quasi-experimental method. The research design was based on a post-test-only control group design. Instruments for collecting data consisted of two types: written tests to assess conceptual understanding and performance assessment sheets to assess the three components of students' 4C skills. The results show that the application of STEM-Smart Physics E-Module positively impacts students' conceptual understanding and three components of the 4C skills, namely creative thinking, critical thinking, and communication.**

***Keywords*—E-module, smartphone, STEM, conceptual understanding, Communication, Collaboration, Critical Thinking, and Creativity (4C) skills**

I. Introduction

The 21st century is known as the technological era [1]. Technological developments have had an impact on the education. Using technology in the learning process can increase student interaction in learning, create more interactive learning, and attract student interest [2, 3]. Improving 21st-century skills is urgently needed to prepare competent students.

The 21st-century skills are often known as 4C skills. The 4C skills include communication, collaboration, critical thinking, and creativity [4]. Communication can be interpreted as a process of language exchange between humans, and communication can be done orally or in writing [5]. Collaboration involves group activities to build and achieve common goals [6]. Critical thinking is one's ability to think systematically and analyze a concept [7]. Creative thinking means generating ideas in new forms to solve problems [8]. These four skills are needed to overcome various challenges and problems.

Learning in the 21st century requires teachers to direct their students to manage everyday problems creatively. Students should be actively involved in learning to construct their conceptual understanding and skills [9]. Students are required to have the ability to use various sources obtained, formulate problems, think analytically systematically and cooperate in solving problems [10, 11].

One way to develop 21st-century skills is by integrating STEM into learning. This will enable students to have a balance between hard skills and soft skills [12]. Student's cognitive abilities can be developed through STEM-integrated learning. These cognitive abilities are 21st-century, including adaptability, complex communication and problem-solving [3]. Thus, STEM applied in 21st-century learning positively impacts students' abilities.

Results of the preliminary study show that physics learning materials in schools have not been able to develop students' interest, motivation and various skills. The analysis of student characteristics in the preliminary study indicates that students' interest and motivation in learning physics can be classified into the low category, with average scores of 53.22 and 53.73, respectively. Previous researchers stated that the low interest and motivation of students to learn was caused by the ineffective use of learning media [13]. In our study population of class XI students, students' learning outcomes and 4C skills were still low. Students learning outcomes in conceptual understanding had an average of 65.63 in the sufficient category.

The results of the performance assessment analysis show that students' critical thinking, creative and communication skills had an average value of 58.23. This average value can be classified into a not-good category. Amran also assessed the 4C skills of students in the schools and found that the students' 4C skills were in the low category [14]. On the other hand, survey results from Yulianti *et al.* state that students' critical thinking skills and creative thinking are included in the low category [15].

The observation results show that finding ways to improve the learning materials is necessary. One way is to develop a STEM-integrated smartphone-based physics E-module (STEM-Smart Physics E-Module). E-modules are learning materials that are combined with the use of technology and are used by students in various places and times [16, 17]. Using an e-module is more interesting than other teaching materials because it is presented with animation, sound, and navigation, making the user more interactive [18, 19]. The advantage of the E-module is that it is connected to the internet and displays videos directly. So, using an E-module causes students to be more active and interactive in the learning process and positively impacts students' abilities, such as knowledge and skills [20].

The problems of the preliminary study showed that science E-modules based on smartphone technology-based teaching are reasonable solutions to be implemented. STEM education in physics learning can achieve the goals of 21st-century skills. STEM education can help students to improve skills 21, including solving real-world problems. Learning materials

doi: 10.18178/ijiet.2024.14.2.2049

teachers use in schools are not under the interests and motivation of student learning. Logical, innovative and productive [21, 22]. This study aims to investigate the impacts of using STEM-Smart Physics E-Module on students' conceptual understanding and 4C skills.

II. Literature Review

The 21st-century use of Information and Communication Technology (ICT) is beneficial and enables the achievement of learning objectives. The large availability of supporting devices, such as smartphones in Indonesia, can be used to introduce E-modules. E-Modules are presentations of self-learning materials that are arranged systematically, and each learning activity is connected with links, animation, video, and audio to add to the learning experience [23, 24]. On the other hand, the learning resources teachers use at schools do not match students' characteristics, so the students' interest and motivation in the learning process are low. Using E-modules has a potential learning material to improve students' motivation [25]. E-modules can be applied to promote the 21st-century skills [26].

STEM integrates the four disciplines of science based on its abbreviation. The STEM approach is often used to solve problems in everyday life. Through the STEM approach, the learning process will go through the application and primary practice of STEM in real life by connecting the four components of STEM [27]. STEM integration in learning is expected to increase the skills needed in the 21st century: student problem-solving, innovation, invention, independence, logical thinking, and technological literacy skills [28].

Teachers must be able to direct and guide students in the learning process to be more creative in managing problems. STEM was developed by connecting the four disciplines of STEM with real-world problems. Students are motivated and encouraged to integrate disciplines from STEM to solve real-world problems, create meaningful learning, and develop their various skills [29–31]. STEM can encourage students to create connections between knowledge and real-world problems, connect science with technology and engineering, connect science and technology with culture, and provide a variety of digital skills [32–34]. Thus, applying STEM in learning can encourage students' various abilities.

Improving students' 21st-century skills is carried out by paying attention to the balance between the scientific approach and the use of communication technology [35, 36]. STEM combines four sub-disciplines of science to explain an event, namely science, technology, engineering and mathematics, to create attractive, meaningful learning and an effect on learning outcomes [37]. Technology is related to human desires or needs. Engineering is a design process that solves problems, and Mathematics learns language in the form of numbers. STEM-integrated learning is a comprehensive educational approach that combines four disciplines of science. Therefore, STEM integration can prepare students to handle challenges and solve problems in the 21st century [38, 39].

Critical thinking and problem-solving are skills that students must have in the challenges of the current era of globalization. Critical thinking is characterized by the ability to recognize and identify problems. Problems should be oriented to students based on their daily lives. Students are motivated and encouraged in the learning process to be able to solve problems using rationale, evaluate ideas and various information, and make rational decisions. Problem-solving and task management can improve critical thinking skills [40].

Creative thinking is the skill of generating ideas analyzing and measuring ideas to improve and maximize tasks [41]. Students must be guided through the assumptions of failure and have the opportunity to learn and also understand that creative thinking as an essential life skill is necessary to provide direction for constantly changing and developing knowledge and emerging problems.

Communication skills are essential and the main requirement that everyone must master. Communication skill is the ability to clearly express one's thoughts, convey opinions, give instructions, and motivate others by exercising excellent communication skills [42]. Students must expand their communication skills to exchange information, feelings and meanings through spoken or written messages.

Collaborating with others is important to achieve success in learning. In learning, a student must be able to ask questions, give opinions, give answers, and so on [43]. The collaboration can be viewed as a mutual involvement to achieve a common goal that involves a variety of respect, trust, responsibility and rules [44]. Therefore, meaningful learning can be created through this collaboration method by rotating minds between students.

Using an E-module integrating communication technology and STEM can promote students' motivation and involvement in learning. They are actively involved in problem-solving to construct conceptual understanding and skills. The use of e-modules can create more meaningful learning. Therefore, the study hypothesizes that STEM-Smart Physics E-Module can promote students' conceptual understanding and 4C skills.

III. Materials and Methods

The research is a quasi-experimental study. A post-test-only design with a control group was used to analyze the impact of STEM-Smart Physics E-Module. The experimental group used a Physics textbook and the STEM Smart Physics E-Module, while the control group used a physics textbook only. The experimental and control groups' initial ability levels were the same before using the STEM-Smart Physics E-Module. The use of STEM-Smart Physics E-Module is carried out in four meetings. The assessment results in the form of questions at the last meeting were used as post-test results.

The study population consisted of five classes at State Senior High School Number 9 in Padang City, with 189 students. They determined that the research sample used cluster random sampling. One-way Anava is applied to ensure the ability of all five classes of students. The results of the one-way ANOVA test indicated that the four classes had the same initial abilities while one class had different abilities. Based on the four classes with the same initial ability, two classes were randomly selected to determine the experimental and control groups. The t-test was applied to both classes to ensure the students' initial abilities were the same. The t-test result showed that the t-test value was 0.80 while the t-table value was 1.69. The result of this t-test indicated no significant difference in the initial abilities of the two groups. Thus, the initial ability of the two groups of students was the same.

The sample group was given different treatment. The experimental group used physics textbooks and STEM-Smart Physics E-Module, while the control group used Physics textbooks in schools. Three experts in the physics department have validated the STEM-Smart Physics E-Module. The validation instrument is developed by gathering relevant theories and obtaining indicator items with an assessment rubric. Experts validated with an average validation value of 0.88 in the good category. The validation results of the STEM-Smart Physics E-Module had an Aikens V value of 0.8 with a valid category.

Data collection methods in the learning process and at the end of learning use instruments. Assessment of students' conceptual understanding abilities was carried out by giving a post-test both in the experimental and control groups. The questions used are valid with a reliability of 0.82 in the high category. On the other hand, the student's skills assessed were three components of 4C skills, including critical thinking, creative thinking and communication,

Collected data were analyzed using descriptive statistical analysis, normality test, homogeneity test and comparison test of two means of the independent group. Descriptive statistical analysis describes the data aspects of conceptual understanding and skills. The normality and homogeneity tests are used to determine the nature of the data distribution and the similarity of the two variances. The normality and homogeneity test results are used as a reference for testing the hypothesis. Comparative tests of two independent group means were used to determine the impacts of using STEM-Smart Physics E-Module on students' critical and creative thinking skills. The data is normally distributed and comes from two data groups with the same variance, so the statistic used is the t-test. Conversely, the U Mann-Whitney statistic is used if the data distribution is not normal and homogeneous.

IV. Results and Discussion

The study results relate to the impacts of STEM-Smart Physics E-Module on aspects of students' conceptual understanding and 4C skills.

A. *Effect of Using the Physics E-Module on Conceptual Understanding*

The first is to carry out a written test in the form of twenty objective questions and five essays to assess aspects of students' understanding of concepts. The results show differences in the average value of the aspect of understanding the concept in the two groups. The results of the statistics analysis of the different aspects of understanding the concepts of the students who use the STEM-smart physics module and students who do not use it are presented in Table 1.

The results of the data analysis in Table 1 show that the data is normally distributed and has the same variance. Testing the hypothesis using a t-test. The calculation results show that the working hypothesis is accepted, which states that there are significant differences in students' understanding of concepts in using the STEM-Smart Physics E-Module.

Table 1. Results of data analysis on the conceptual understanding

	Statistical Parameters	Experimental Group	Control Group
Descriptive Statistics	a. n	38	40
	b. Mean	78.97	73.9
	c. Modus	87	74
	d. S	14.16	15.76
	e. S^2	200,46	248.25
Normality Test	a. α	0.05	0.05
	b. L_0	0.12	0.13
	c. L_t	0.14	0.14
	d. Explanation	Normally	Normally
Homogeneity Test	a. α	0.05	0.05
	b. F_h	0.86	
	c. F_t	1.05	
	d. Explanation	Homogeneous	
T-test	a. α	0.05	0.05
	b. t-test	3.08	
	c. t-table	1.99	
	d. Explanation	Different	

The use of STEM-Smart Physics E-Module positively impacts aspects of students' conceptual understanding. STEM integration in smartphone-based e-modules enables students to engage in learning and technology practice in a social context. STEM integration provides meaningful learning for students through the systematic integration of conceptual understanding [45]. In addition, the smartphone-based physics E-Module increases students' motivation in learning activities. This is because E-modules are interactive learning media [46].

B. *Effect of Physics E-Module on Critical Thinking Skills*

The critical thinking component has four assessment indicators. The indicators for this performance assessment are Asking Questions (ASQ), Looking for Alternatives (LFA), answering questions (ANQ) and Looking for Reasons (LFR) [47, 48]. The data analysis results on the two groups' critical thinking skills can be seen in Fig 1.

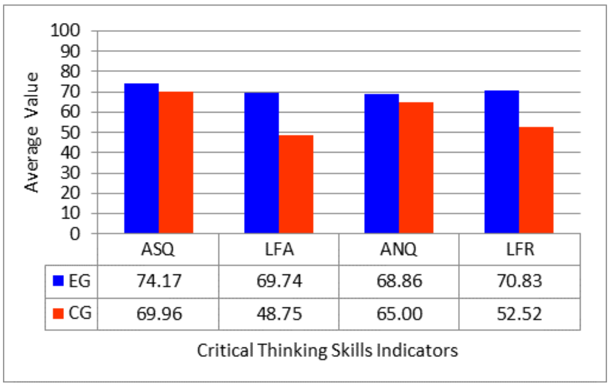

Fig. 1. Value indicators of critical thinking skills.

Based on the data in Fig. 1, the value of the four indicators of critical thinking. The indicator that gets the highest score is the indicator asking questions. Indicators that need to be improved are indicators of looking for alternatives and indicators of answering questions. The average value of the four critical thinking indicators in the experimental group was

70.90, while in the control group, it was 59.06. This shows differences in the scores obtained by students who use the STEM-Smart Physics E-Module. The analysis results of students' critical thinking skills are described in Table 2.

Table 2. Results of data analysis of critical thinking skills

	Statistical Parameters	Experimental Group	Control Group
Descriptive Statistics	a. n	38	40
	b. Mean	70.90	59.06
	c. Modus	68.75	56.06
	d. S	8.53	6.90
	e. S^2	72.76	47.61
Normality Test	a. α	0.05	0.05
	b. L_0	0.09	0.12
	c. L_t	0.14	0.14
	d. Explanation	Normally	Normally
Homogeneity Test	a. α	0.05	0.05
	b. F_h	0.86	
	c. F_t	1.05	
	d. Explanation	Homogeneous	
T-test	a. α	0.05	0.05
	b. t-test	5.43	
	c. t-table	1.99	
	d. Explanation	Different	

From the results of Table 2, the data on aspects of critical thinking skills from the two sample groups can be classified into normal and homogeneous categories. Based on these results, the comparison test of the two means is the t-test. The calculations show significant differences in the aspects of students' critical thinking abilities in using the STEM-Smart Physics E-Module. Thus, students critical thinking skills in learning positively impact the use of the STEM Smart Physics E-Module.

The use of STEM-Smart Physics E-Module positively affects students' critical thinking. This is because learning physics using smartphone-based E-modules integrated with STEM encourages students to analyze [49]. Students think reflectively in decision-making and problem-solving to analyze situations [50], look for alternatives and evaluate arguments in drawing the correct conclusions [51]. Individuals who can think analytically can conclude something already known, know how to present information in solving problems and find relevant sources of information [52]. Thus, using STEM-Smart Physics E-Module effectively promotes the student's critical thinking skills of class XI high school.

C. Effects of Physics E-Module on Creative Thinking Skills

The creative thinking component has four assessment indicators. A performance assessment sheet is used to measure students' creative thinking skills. The assessment indicators are Asking Lots of Questions (ALQ), Giving Various Ways (GVW), Giving Lots of Answers (GLA) and Giving Various Reasons (GVR) [53]. The results of the analysis of the creative thinking component of students can be seen in Fig. 2.

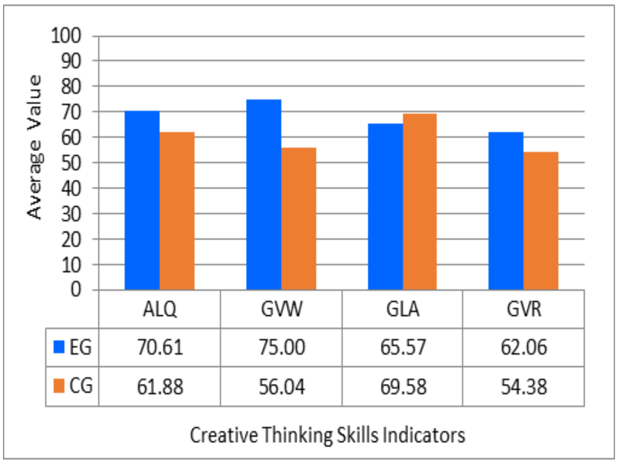

Fig. 2. Value of indicators of creative thinking skills.

The results of the data analysis in Fig. 2 illustrate the comparison of the values of the four indicators of creative thinking in the experimental group and the control group. The highest indicator is given in various ways. In comparison, the indicators that still have a low score ask many questions. Students are still limited to giving questions, only one method and reason. It is expected that students can provide more than one question, method and reason. This is what makes the three assessment indicators have a low score. The mean scores of the four indicators of creative thinking in the experimental group and the control group were 68.31 and 60.47, respectively. That data shows a significant difference in the scores obtained after using the STEM-Smart Physics E-Module. The analysis results of students' critical thinking skills are described in Table 3.

Table 3. Results of data analysis of creative thinking skills

	Statistical Parameters	Experimental Group	Control Group
Descriptive Statistics	a. n	38	40
	b. Mean	68.31	60.47
	c. Modus	75	62.5
	d. S	8.26	6.97
	e. S^2	68.31	48.63
Normality Test	a. α	0.05	0.05
	b. L_0	0.1	0.13
	c. L_t	0.14	0.14
	d. Explanation	Normally	Normally
Homogeneity Test	a. α	0.05	0.05
	b. F_h	0.71	
	c. F_t	1,05	
	d. Explanation	Homogeneous	
T-test	a. α	0.05	0.05
	b. t-test	8.87	
	c. t-table	1.99	
	d. Explanation	Different	

From the results of Table 3, it can be stated that the data on aspects of creative thinking skills from both normal and homogeneous sample classes. A two-mean comparison test was carried out based on these results, namely the t-test. The calculation results show a significant difference in the creative thinking aspects of students who use the STEM-Smart Physics E-Module. Thus, using the STEM-Smart Physics E-Module effectively can improve students' creative thinking skills.

The creative thinking component significantly differed after students used the STEM-Smart Physics E-Module. STEM integration in learning can improve students' creative thinking abilities. Creative thinking skills need to be improved for students to be better because, during the revolutionary era, the development of the times was very significant, especially in education. Students are required to be able to adapt to the world of education in this era. One way is that students must be able to think creatively to find new things appropriate for today's world of education. An alternative way to improve students' creative thinking skills is to implement the STEM approach in learning [54]. This integrates the use of STEM-Smart Physics E-Module, which effectively promotes the students' creative thinking skills of class XI high school.

D. Effects of Physics E-Module on Communication Skills

The communication skills component has four assessment indicators. The indicators for this assessment are using Capital Letters (CL), using Punctuation Mark (PM), using Correct Conjunction (CC) and Concluding Information (CI) in symbols and words [55]. The analysis results of students' communication skills components can be presented in Fig. 3.

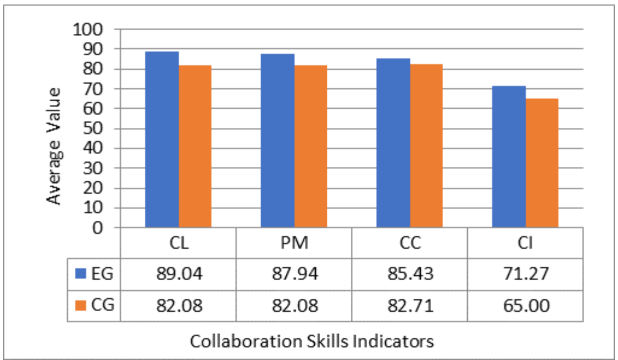

Fig. 3. The value of communication skill indicators.

Data analysis in Fig. 3 shows that the comparison of the values of the four indicators of communication skills from the two groups has different values. The result of the analysis of the experimental group with the highest indicator uses capital letters. Furthermore, the lowest indicator is concluding information in symbols and words. Students can communicate in writing well, but the use of writing symbols still needs to be improved. The average value of the four indicators of students' communication skills in the experimental group and the control group were 83.44 and 77.97. These results indicate that the average value of students' communication skills who use the STEM-Smart Physics E-Module is higher than those who do not. The results of the analysis of student's communication skills are presented in Table 4.

Table 4. Results of data analysis of communication skills

	Statistical Parameters	Experimental Group	Control Group
Descriptive Statistics	a. n	38	40
	b. Mean	83.44	77.97
	c. Modus	89.58	85.42
	d. S	12.24	12.76
	e. S^2	149.9	162.9
Normality Test	a. α	0.05	0.05
	b. L_0	0.18	0.15
	c. L_t	0.14	0.14
	d. Explanation	Not Normally	Not Normally
Homogeneity Test	a. α	0.05	0.05
	b. F-test	1.09	
	c. F-table	1.05	
	d. Explanation	Not Homogeneous	
Mann-Whitney test	a. α	0.05	0.05
	b. t-test	−6.08	
	c. t-table	−1.96	
	d. Explanation	Different	

The average value of aspects of student communication skills in classes that use the STEM-Smart Physics E-Module is higher than the group that does not use it. The data on communication skills from the two sample groups is not normal and not homogeneous. Based on the results of these two tests, the statistical test used is the Mann-Whitney U test. The Z-table value of −6.08 is outside the null hypothesis acceptance area. In other words, the working hypothesis is accepted. Based on this, there were significant differences between the two classes in the use of the STEM-integrated physics E-module. Thus, the use of the STEM-Smart Physics E-Module is effective in improving students' communication skills.

The communication skills component significantly differed after students used the STEM-Smart Physics E-Module. Learning activities in the physics E-module have worksheets for experiment activities [56]. After carrying out experiment activities, students make experiment reports. Students' written communication skills can be observed when answering questions in writing and making activity reports [57]. Based on the results obtained, students' analytical communication skills are good. Students' written communication skills can be explained by analytical thinking skills [58]. Integrates the effective use of STEM-Smart Physics E-Module to promote the students' communication skills.

In 21st-century skills, there is a significant difference between the control and experimental classes whose students use the STEM-Smart Physics E-Module. Compared to the three components of students' 21st-century skills, the improvement in critical thinking is more dominant than creative thinking. This can happen because the STEM-integrated physics e-module trains students to solve problems that exist in the real world. This is confirmed by Wahyuni *et al.*, who state that students' critical thinking can be raised and trained when someone is faced with a problem [59].

The components of creative thinking skills and students' communication skills also increased. The increased creative thinking is not very significant because students are still limited in finding many ways and reasons. A person is said to be creative if he can formulate new and unique ways and reasons [60]. Besides that, in the communication skills component, students can already make practicum reports per the correct writing standards.

The results of the research carried out are from previous research. First, STEM-based modules can increase student learning activities, critical thinking skills and positive responses to applying STEM-based learning modules [61]. Second, the STEM approach effectively improves students' 21st-century skills, namely students' critical thinking skills [62]. All of these aspects show that the STEM-Smart Physics E-Module has quality and can be used as a solution in handling the challenges of the 21st century, one of which is its ability to improve aspects of skills and learning outcomes of the 21st century.

This study is still limited to learning materials and components of 21st-century skills. The follow-up of the research is to develop STEM-smart Physics e-modules for other physics materials and various relevant skills. Besides that, this research can be continued by designing innovative learning to implement this STEM-smart Physics E-module.

V. Conclusions

There are two results of the research data analysis carried out. First, the use of the STEM-Smart Physics E-Module has a positive impact on students' conceptual understanding. Second, using the STEM-Smart Physics E-Module positively impacts three components of the students' 4C skills: critical thinking, creative thinking, and communication. These results indicate that using the STEM-Smart Physics E-Module can promote students' conceptual understanding and 4C skills. For this reason, teachers can utilize STEM-Smart Physics E-Module to enhance the quality of physics education and promote students' comprehension of concepts and skills relevant to the 21st century.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Asrizal contributed in managing research including planning, implementation, reporting, and publication of research results. N. Nazifah contributed in designing and creating the STEM-Smart Physics E-Module, developing the data collection instruments, carrying out research activities, reporting research results, and writing manuscript draft. H. Effendi contributed to develop of two STEM components, namely technology and engineering. Helma contributed to develop the mathematics component of the STEM. All authors had approved the final version

References

[1] R. Raja and P. C. Nagasubramani, "Impact of modern technology in education," *Journal of Applied and Advanced Research*, vol. 3, no. 1, pp. 33–35, 2018.

[2] D. Bogusevschi, C. Muntean, and G. M. Muntean, "Teaching and learning physics using 3D virtual learning environment: A case study of combined virtual reality and virtual laboratory in secondary school," *Journal of Computers in Mathematics and Science Teaching*, vol. 39, no. 1, pp. 5–18, 2020.

[3] A. Asrizal, Y. Yurnetti, and E. A. Usman, "ICT thematic science teaching material with 5E learning cycle model to develop students' 21st-century skills," *Jurnal Pendidikan IPA Indonesia*, vol. 11, no. 1, pp. 61–72, 2022.

[4] R. Rudianti, R. Diani, S. Subandi, and N. Widiawati, "Development of assessment instruments 4C skills (critical thinking, collaboration, communication, and creativity) on parabolic motion materials," *Journal of Advanced Sciences and Mathematics Education*, vol. 2, no. 2, pp. 65–79, 2022.

[5] M. Rahimi and J. Fathi, "Employing e-tandem language learning method to enhance speaking skills and willingness to communicate: The case of EFL learners," *Computer Assisted Language Learning*, pp. 1–37, 2022.

[6] M. Á. Herrera-Pavo, "Collaborative learning for virtual higher education," *Learning, Culture and Social Interaction*, vol. 28, 100437, 2021.

[7] E. Evendi, M. H. H. Pardi, L. Sucipto, F. Bayani, and S. Prayogi, "Assessing students' critical thinking skills viewed from cognitive style: Study on implementation of problem-based e-learning model in mathematics courses," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 18, no. 7, em2129, 2022.

[8] N., Sirajudin and J. Suratno, "Developing creativity through STEM education," in *Journal of Physics: Conference Series*, March 2021, IOP Publishing, vol. 1806, no. 1, 012211.

[9] H. Zhang and Y. Li, "Integrating active learning activities and metacognition into STEM writing courses." *Advances in Physiology Education*, vol. 45, no. 4, pp. 902–907, 2021.

[10] I. Rahmania, "Project based learning (PjBL) learning model with STEM approach in natural science learning for the 21st century," *Budapest Int. Res. Critics Inst. Humanit. Soc. Sci*, vol. 4, no. 1, pp. 1161–1167, 2021.

[11] G. Falloon, M. Hatzigianni, M. Bower, A. Forbes, and M. Stevenson, «Understanding K-12 STEM education: A framework for developing STEM literacy," *Journal of Science Education and Technology, vol.* 29, no. 3, pp. 369–385, 2020.

[12] S. Lugthart and M. van Dartel, "Simulating professional practice in STEAM education: A case sudy," *European Journal of STEM Education*, vol. 6, no. 1, p. 17, 2021.

[13] O. S. Kaya and E. Ercag, "The impact of applying challenge-based gamification program on students' learning outcomes: Academic achievement, motivation and flow," *Education and Information Technologies*, pp. 1–26, 2023.

[14] A. Amran, M. Perkasa, M. Satriawan, I. Jasin, and M. Irwansyah, "Assessing students 21st century attitude and environmental awareness: promoting education for sustainable development through science education," *Journal of Physics: Conference Series*, vol. 1157, pp. 1–5, February 2019.

[15] D. Yulianti, S. Sugianto, and K. M. Ngafidin, "Scratch assisted physics learning with a STEM approach in the pandemic era to develop 21st century learning skills," *Jurnal Pendidikan IPA Indonesia*, vol. 11, no. 1, pp. 185–194, 2022.

[16] N. I. Wahidah, N. T. Sakung, I. Festiana, W. A. Rikarda, I. Iskandar, and A. Komarudin, "Analysis of needs in the development of website-based e-modules for self-study," *International Journal of Education, Information Technology and Others (IJEIT)*, vol. 4, no. 4, pp. 667–673, 2021.

[17] M. Hendri, D. P. Rasmi, and W. Ananda, "Analysis of the needs of developing teaching materials in the form of STEM-based web modules using scaffolding," *Journal of Research in Science Education*, vol. 7, special issues, pp. 139–144, 2021.

[18] R. Sidiq, N. Najuah, and P. Suhendro, "Utilization of interactive e-modules in formation of students' independent characters in the era of pandemic," *International Journal of Educational Research & Social Sciences*, vol. 2, no. 6, pp. 1651–1657, 2021.

[19] L. T. S. Wahyuni and I. B. P. Arnyana, "E-module based on *tri kaya parisudha* effectively improves science learning outcomes," *Mimbar PGSD Undiksha*, vol. 10, no. 2, pp. 358–366, 2022.

[20] A. Q. Nada, M. R. A. Taqwa, E. Supriana, and P. Suwasono, "Development of an android-based physics interactive e-module equipped with problems with scaffolding in applying the concept of light waves," *International Journal of Education and Teaching Zone*, vol. 1, no. 2, pp. 159–178, 2022.

[21] D. E. Liana, M. Muzzazinah, and M. Indrowati, "Development of e-modules based on guided inquiry to improve students' critical

thinking ability," in *Proc. 2nd Basic and Applied Science Conference (BASC)*, 2022, pp. 29–37.

[22] W. N. F. W. Husin, N. M. Arsad, O. Othman, L. Halim, M. S. Rasul, K. Osman, and Z. Iksan, "Fostering students' 21st century skills through Project Oriented Problem Based Learning (POPBL) in integrated STEM education program," *Asia-Pacific Forum on Science Learning & Teaching*, vol. 17, no. 1, June, 2016.

[23] R. Rifandi and Y. L. Rahmi, "STEM education to fulfil the 21st century demand: A literature review," in *Journal of Physics: Conference Series*, IOP Publishing, October 2019, vol. 1317, no. 1, 012208.

[24] A. Asrizal and A. W. Utami, "Effectiveness of mechanical wave learning material based on ICT integrated CTL to improve students learning outcomes," *Jurnal Penelitian Pendidikan IPA*, vol. 7, no. 4, 632–641, 2021.

[25] R. Sidiq, N. Najuah, and P. Suhendro, "Utilization of interactive e-modules in formation of students' independent characters in the era of pandemic," *International Journal of Educational Research & Social Sciences*, vol. 2, no. 6, pp. 1651–1657, 2021.

[26] Y. A. A. Ndoa and J. Jumadi, "Increasing learning motivation through the application of physics e-module based on flipped learning," *Jurnal Penelitian Pendidikan IPA,* vol. 8, no. 3, pp. 1223–1230, 2022.

[27] W. Widya, D. Maielfi, A. Alfiyandri, and W. Hamidah, "Creative problem solving-based electronic module integrated with 21st century skills," *Indonesian Journal of Science and Mathematics Education*, vol. 4, no. 3, pp. 333–342, 2021.

[28] R W. Bybee, *The Case for STEM Education: Challenges and Opportunities*, Arlington-Virginia: National Science Teachers AssoNciation Press, 2013.

[29] A. Eguchi, "Bringing robotics in classrooms," in *Robotics in STEM Education*, Springer, 2017, pp. 3–31.

[30] N. H. Astuti, A. Rusilowati, and B. Subali, "STEM-based learning analysis to improve students' problem-solving abilities in science subject: a literature subject," *Journal of Innovative Science Education*, vol. 10, no. 1, pp. 79–86, 2021.

[31] S. M. Jamali, M. A. Ebrahim, and F. Jamali, "The role of STEM education in improving the quality of education: A bibliometric study," *International Journal of Technology and Design Education*, vol. 32, no. 3, pp. 1–31, 2022.

[32] A. Asrizal, V. Mardian, F. Novitra, F. Festiyed, "Physics electronic teaching material-integrated STEM education to promote 21st-century skills," *Cypriot Journal of Educational Sciences*, vol. 17, no. 8, pp. 2899–2914, 2022.

[33] E. A. Dare, K. Keratihamkul, B. M. Hiwatig, F. Li, "Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education," *MDPI Education Sciences*, vol. 11, no. 11, pp. 1–22, 2021.

[34] T. P. L. Nguyen, T. H. Nguyen, and T. K. Tran, "STEM education in secondary schools: teachers' perspective towards sustainable development. *MDPI Sustainability*, vol. 12, no. 21, pp. 1–16, 2020.

[35] K. Smith, N. Mainard, A. Berry, T. Stephenson, T. Spiteri, D. Corrigan, J. Mansfield, P. Ellerton, and T. Smith, "Principles of problem-based learning (PBL) in STEM education: using expert wisdom and research to frame educational practice," *MDPI Educational Sciences*, vol. 12, no. 10, pp. 1–20, 2022.

[36] F. Novitra, "Development of online-based inquiry learning model to improve 21st-century skills of physics students in senior high school," *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 17, no. 9, 2021.

[37] B. Granovskiy, "Science, Technology, Engineering, and Mathematics (STEM) education: An overview," CRS Report R45223, version 4. updated, *Congressional Research Service*, 2018.

[38] Y. A. Yilmaz, J. Cakiroglu, H. Ertepinar, and S. Erduran, "The pedagogy of argumentation in science education: science teacher's instructional practices," *International Journal of Science Education*, pp. 1–22, 2017.

[39] G. Falloon, M. Hatzigianni, M. Bower, A. Forbes, and M. Stevenson, "Understanding K-12 STEM education: A framework for developing STEM literacy," *Journal of Science Education and Technology*, vol. 29, no. 3, pp. 369–385, 2020.

[40] E. Nurhayati, D. R. Rizaldi, and Z. Fatimah, "The correlation of digital literation and STEM integration to improve Indonesian students' skills in 21st century," *Online Submission*, vol. 1, no. 2, pp. 73–80, 2020.

[41] F. M. Zain, Z. Osman, N. H. I. M. Kasim, and F. Ab Rahman, "Edmodo as a 21st century Learning tool to enhance 4C skills of Malay language management undergraduates," *International Journal of Information and Education Technology*, vol. 13, no. 7, 2023.

[42] C. C. Leen, K. F. F. H. Hong, and T. W. dan Ying, *Creative and Critical Thinking in Singapore Schools*, Singapore: Nanyang Technological University, 2014.

[43] N. W. Rati, I. B. P. Arnyana, G. R. Dantes, and N. Dantes, "HOTS-oriented e-project-based learning: Improving 4C skills and science learning outcome of elementary school students," *International Journal of Information and Education Technology*, vol. 13, no. 6, 2023.

[44] L. Sriphong, S. Niratisai, and C. Sukonpan, "Effective collaborative learning through online flipped laboratory amid the COVID-19 pandemic," *International Journal of Information and Education Technology*, vol. 12, no. 5, 2022.

[45] B. Thornhill-Miller, A. Camarda, M. Mercier, J. M. Burkhardt, T. Morisseau, S. Bourgeois-Bougrine, and T. Lubart, "Creativity, critical thinking, communication, and collaboration: assessment, certification, and promotion of 21st Century skills for the future of work and education," *Journal of Intelligence*, vol. 11, no. 3, p. 54, 2023.

[46] N. A. Rahman, R. Rosli, A. S. Rambely, and L. Halim, "Mathematics teachers' practices of STEM education: A systematic literature review," *European Journal of Educational Research*, vol. 10, no. 3, pp. 1541–1559, 2021.

[47] H. Nurhikmah, A. Hakim, and M. S. Wahid, "Interactive e-module development in multimedia learning," *Al-Ishlah: Jurnal Pendidikan*, vol. 13, no. 3, pp. 2293–2300, 2021.

[48] R. Ennis, "Critical thinking: Reflection and perspective Part I," *Inquiry: Critical Thinking across the Disciplines*, vol. 26, no. 1, pp. 4–18, 2011.

[49] K. K. Papp, G. C. Huang, L. L. M. Clabo, D. Delva, M. Fischer, I. Konopasek, R. M. Schwartzsein, and M. dan Gusic, "Milestones of critical thinking: A developmental model for medicine and nursing," *Academic Medicine*, vol. 89, no. 5, pp. 715–720, 2014.

[50] F. S. Kartini, A. Widodo, N. Winarno, and L. Astuti, "Promoting student's problem-solving skills through STEM project-based learning in earth layer and disasters topic," *Journal of Science Learning*, vol. 4, no. 3, pp. 257–266, 2021.

[51] E. Reyes-Chua, N. Navigar, M. J. Campaña, R. Ymana, R. J. M. Ventayen, and I. C. Ymana, "Reflective critical thinking skills of student leaders in higher education institutions for development," *WSEAS Transactions on Environment and Development*, vol. 17, 2021.

[52] E. Cahya and D. Juandi, "Students' critical thinking skills in solving mathematical problems: A systematic procedure of grounded theory study," *International Journal of Instruction*, vol. 14, no. no. 4, pp. 529–548, 2021.

[53] N. Gerungan, M. Muntuuntu, and R. Rorimpandey, "An analysis of students'level of critical thinking in final exam," *JoTELL: Journal of Teaching English, Linguistics, and Literature*, vol. 1, no. 1, pp. 157–174, 2022.

[54] T. Y. Siswono, "Identifying creative thinking process of students through mathematics problem posing," in *Proc. the International Conference on Statistics and Mathematics and Its Application in the Development of Science and Technology*, Bandung Islamic University, 2004.

[55] M. P. Hasibuan, R. P. Sari, R. A. Syahputra, and N. Nahadi, "Application of integrated project-based and stem-based e-learning tools to improve students' creative thinking and self-regulation skills," *Jurnal Penelitian Pendidikan IPA*, vol. 8, no. 1, pp. 51–56, 2022.

[56] L. Greenstein, *Assessing 21 Century Skills: A* Guide *to Evaluating Mastery and Authentic Learning*, California: Corwin, 2012.

[57] A. Defianti, D. H. Putri, S. Rohayati, A. Herawati, and L. Y. Chen, "Development of e-module guideline on basic physics practicum for science process skills in a pandemic period," *Journal of Natural Science and Integration*, vol. 5, no. 1, pp. 45–56, 2022.

[58] M. D. Wulandari, S. Sarwi, and A. Yulianto, "Development of discovery learning model using scientific approach to increase students comprehension and communication skills," *Journal of Innovative Science Education*, vol. 7, no. 2, pp. 223–228, 2018.

[59] M. J. Bezanilla, D. Fernández-Nogueira, M. Poblete, and H. Galindo-Domínguez, "Methodologies for teaching-learning critical thinking in higher education: The teacher's view," *Thinking Skills and Creativity*, vol. 33, 2019.

[60] S. Wahyuni, I. G. M. Sanjaya, E. Erman, and B. Jatmiko, "Edmodo-based blended learning model as an alternative of science learning to motivate and improve junior high school students' scientific critical thinking skills," *International Journal of Emerging Technologies in Learning (Online)*, vol. 14, no. 7, p. 98, 2019.

[61] I. Supena, A. Darmuki, and A. Hariyadi, "The Influence of 4C (Constructive, Critical, Creativity, Collaborative) Learning Model on

Students' Learning Outcomes," *International Journal of Instruction*, vol. 14, no. 3, pp. 873–892, 2021.
[62] A. N. Pane, D. Andra, and I. W. Distrik, "The development physics e-module based PBL–Integrated STEM to improve higher-order thinking skills on static fluid material," in *Journal of Physics: Conference Series*, IOP Publishing, February 2021, vol. 1796, no. 1, 012086.