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Leveraging interactive e-learning platforms to enhance problem-solving ability in science learning: A pathway to achieving SDG 4 for quality education

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Abstract

The global education system, especially in Indonesia, needs help to enhance students problem-solving skills, a key aspect of SDG 4: Quality Education. Traditional teaching methods have proven inadequate in developing students' problem-solving in complex science topics like the circulatory system, highlighting the need for more effective, innovative solutions. This study aimed to analyze the effectiveness of STEAM-based e-modules in enhancing problem-solving skills among fifth-grade students and to assess the contribution of STEAM-based e-modules to achieving the Sustainable Development Goals (SDGs) within the context of primary education. This research employed an experimental design, specifically a True Experimental design with a Pretest-Posttest Control Group Design. The experimental group used STEAM-based e-modules installed on their devices as learning materials, while the control group used printed textbooks. One hundred two fifth-grade students participated, and the study was conducted at Supriyadi Elementary School in Semarang. The results indicated that students who used the STEAM-based e-modules showed significant improvement in all problem-solving indicators, with an overall increase of 0.68, which falls within the "medium" range but approaching a "high" criterion. In contrast, students who used printed textbooks also showed improvement, but their increase was only 0.28, which falls within the "low" range. Using STEAM-based e-modules significantly contributes to achieving Sustainable Development Goal 4 by enhancing students problem-solving skills and providing an inclusive and equitable approach to quality education in primary schools. In conclusion, using STEAM-based e-modules supported sustainable learning by enhancing students problem-solving abilities and contributing to quality education in primary schools.

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Keywords

E-modules, Primary education, Problem-solving, SDG 4, STEAM

Introduction

Global education faces significant challenges as societies evolve towards Society 5.0, an era with digital technology and artificial intelligence (AI) becoming integral parts of daily life [1]. In contrast to the Industrial Revolution 4.0, which focused on automation and digitalization [2], Society 5.0 prioritizes using technology to enhance the quality of life, fostering inclusive, innovative, and sustainable societies [3]. In this context, education is focused on mastery of knowledge [4] and developing critical competencies necessary to address complex educational issues and challenges [5]. The capacity to solve problems effectively is crucial [6], as it determines the ability of individuals to adapt to a rapidly changing and uncertain global environment [7].

Problem-solving competency aligns with broader global objectives, specifically the Sustainable Development Goals (SDGs), particularly SDG 4: Quality Education [8]. SDG 4 emphasizes the importance of providing inclusive, equitable, and quality education for all, aiming to enhance 21st-century skills required to compete in an increasingly digital and globalized world [9]. As one of the keys 21st-century skills, problem-solving must be an integral part of the elementary education curriculum [10]. It is crucial, given that future challenges in the workforce and daily life will necessitate the ability to think critically and creatively and solve unexpected problems [11]. Therefore, developing problem-solving competencies from an early age at the elementary school level becomes a primary priority in supporting the achievement of SDG 4 in Indonesia [12].

Despite a strong commitment to achieving SDG 4 by 2030 in Indonesia, the reality reveals a significant educational quality gap, particularly at the elementary school level [13]. Research conducted by the Ministry of Education and Culture (2023) indicates that problem-solving competencies among Indonesian elementary school students still need to improve. Furthermore, according to the Program for International Student Assessment (PISA) report by the OECD in 2018, Indonesia was ranked relatively low in science literacy and problem-solving skills [14]. These results reflect that many Indonesian students, especially at the elementary level, have yet to master fundamental critical thinking and problem-solving skills for facing global challenges [15].

Competency assessment results at Supriyadi Elementary School in Semarang indicate that most fifth-grade students need help solving problems that require analytical thinking and creative solutions. These findings emerged from pre-research interviews with fifth-grade teachers. Furthermore, teachers revealed that the problem-solving competencies of fifth-grade students still need to be considered satisfactory. Teachers reported that students need help understanding and applying the concept of human blood circulation, a complex subject that demands high analytical and critical thinking abilities. The situation highlights a gap between existing teaching practices at the school and the problem-solving competencies that should be achieved according to national and international standards. It also reflects broader challenges in Indonesia, where traditional teaching methods remain dominant [16] and are less effective in developing problem-solving competencies [17].

In response to the challenges related to the inefficacy of traditional teaching methods, using digital technology in education emerges as a highly relevant and urgent solution [18]. Digital technologies, particularly interactive e-learning platforms, can provide more engaging and contextualized learning approaches [19]. One effective strategy is using STEAM-based e-modules (Science, Technology, Engineering, Arts, and Mathematics) [20]. STEAM, an interdisciplinary educational framework that combines multiple disciplines, aims to enrich students' knowledge [21] and develop essential competencies such as creativity, critical thinking, and problem-solving [22]. STEAM-based e-modules developed and validated by experts offer innovative solutions to address the complexity of human blood circulation in a more interactive and applicative manner [23].

Despite various efforts to enhance the quality of science education in Indonesia, a gap exists between current teaching practices and the competencies required in the 21st century [24]. Previous research by Triwahyuningtyas, Ningtyas and Rahayu [25], indicates that traditional teaching methods remain dominant in many Indonesian elementary schools, which are less effective in developing students' problem-solving competencies. Additionally, [26] identified that integrating STEAM into science education can improve students' critical and creative thinking abilities; however, its implementation still needs to be improved across different regions of Indonesia [27].

The need for innovative solutions, such as using STEAM-based e-modules, has become increasingly urgent [28]. The e-module is designed explicitly for human blood circulation, developed and validated by experts, and undergoing practicality testing. STEAM-based e-modules are expected to provide a more interactive and contextualized learning approach, enhancing fifth-grade students' understanding and problem-solving competencies [29] at Supriyadi Elementary School in Semarang. Such an innovative solution is relevant for addressing issues at that particular school [30] and can serve as a model for other schools in Indonesia in efforts to achieve SDG 4.

The urgency of the present research is heightened by the fact that problem-solving competency is essential for students to navigate the complex challenges of the Society 5.0 era [10]. The development of this competency is fundamental to academic achievement, personal growth, and students' ability to adapt to the rapidly changing social and technological landscapes [31]. Furthermore, another aspect of its urgency is that this study directly supports the achievement of SDG 4 by focusing on enhancing the quality of education [32] through the development of relevant problem-solving abilities. Implementing digital technology in science education at the elementary level can serve as a replicable model for other schools to achieve quality education goals [21]. Furthermore, this research will provide an innovative solution to the complex subject matter, specifically human blood circulation, which requires an interactive and contextualized learning approach. Using STEAM-based e-modules offers a creative solution to improve students' understanding of the materials and develop their analytical and problem-solving abilities [33]. Additionally, more research is needed to examine the effectiveness of STEAM-based e-modules in enhancing problem-solving competencies at the elementary school level in Indonesia [34]. This study will bridge that gap by providing empirical data and relevant contextual analysis, particularly at Supriyadi Elementary School in Semarang.

Prior studies have highlighted the importance of integrating digital technology and the STEAM approach in science education [35]. Khikmiyah, Rusijono, and Arianto [27], in their research on STEAM integration in elementary schools, found that this approach significantly enhances students' critical and creative thinking skills. Utaminingsih [29] their study on implementing interactive e-modules in biology education demonstrated that these modules enhance students' conceptual understanding and capacity to apply knowledge effectively.

In Indonesia, research by [36] indicates that STEAM integration remains limited and often poorly structured; its effectiveness in enhancing students' science competencies has yet to be maximized. Additionally, [37] emphasizes that traditional teaching methods are still dominant and less effective in developing students' problem-solving competencies. Seruni [19] also indicates that the use of digital technology in science education at Indonesian elementary schools still needs various obstacles, such as a lack of teacher training and limitations in technological infrastructure. This study will complement existing literature by explicitly examining the effectiveness of STEAM-based e-modules in enhancing the. problem-solving competencies of fifth-grade students at Supriyadi Elementary School in Semarang. Thus, this research contributes to theoretical development and provides practical solutions that can be implemented in the Indonesian elementary education environment.

The study aimed to analyze whether the STEAM-based e-modules learning process could improve fifth-grade students' problem-solving abilities at Supriyadi Elementary School, Semarang. The findings of this research are poised to offer a significant contribution to elementary education in Indonesia, particularly in advancing students' problem-solving competencies through the application of digital technology. The findings of this study serve as a reference for designing and developing more effective e-learning platforms for science education and enhancing problem-solving abilities. Additionally, this research will support the achievement of SDG 4 in Indonesia, which emphasizes the importance of quality and inclusive education. Consequently, this study will benefit not only Supriyadi Elementary School in Semarang but also other elementary schools in Indonesia that are facing similar challenges.

Method

Design Research

This study uses an experimental type of research with a True experimental design type, i.e., Pretest-Posttest Control Group Design. This research has been conducted in Semarang City at Supriyadi Elementary School, Semarang. The design of this study refers to [38], has two groups selected with special considerations. In addition, two groups of samples, experimental and control, were homogeneous (had the same characteristics). The implementation begins with the provision of a pre-test with the same test in both groups, then different needs are given in each group; after learning, a post-test is given to analyze differences and improvements.

Population and Sample

The population in the study is class V of Supriyadi Elementary School Semarang. As for the sampling technique used, purposive sampling. The sample calculation technique uses the Slovin formula [39] where the calculation is presented in Eq.1.

n = $\frac{N}{N.e^2+1}$ .... (Eq.1)

Description: N as Number of Samples; N as Number of Populations; E as The desired critical value (error limit) is 8%. From the formula above, the following numbers are obtained:

n = $\frac{137}{137.(0,05)^2+1}$

n = $\frac{137}{137.0,0025+1}$

n = $\frac{137}{1,3425}$

n = 102

Based on the calculation using the Slovin formula, a sample of 102 students was obtained.

Data Collection Instruments

Instruments for pre-test and post-test developed by Utaminingsih [40]. The problem-solving question items to be used have gone through the validity stage which was assessed by four validators and declared valid. The results of the validity were analyzed using the v-Aiken formula and a final value of 0.92 was obtained. In addition to the analysis using the v-Aiken formula, the validation results of the experts were also assessed based on the Kappa Statistical Coefficient. *Content Validity Coefficient* (CVI) was declared valid, and the validity status category was declared almost perfect. In addition, the analysis results using the Statistical Package for the Social Sciences (SPSS) 25 were declared valid because each question item had a validity value above 0.355 with the number of test respondents as many as 31). Each question item was also tested by Cronbach's Alpha (α), which obtained a score of 0.712 and was declared reliable. The difficulty level of the question items is proportional 3: 4: 3, it means that the instrument is declared valid and suitable. The purpose of the pre-test is to determine the student's initial state.

Learning Process

The learning process is divided into 2 groups: an experimental group and a control group. The experimental group learns using e-modules installed on their students' gadgets while the control group learns using books. The design of the Pretest-Posttest Control Group is presented in Table 1 in detail.

Table 1. Pretest-Posttest Control Group Design

Group	Pre-test	Treatment	Post-test
Experiment	O_1	X_1	O_2
Control	O_3	X_2	O_4

Description:

X_1 : Giving treatment (X_1), i.e., the provision of material with e-modules STEAM-based against research samples

X_2 : Giving treatment (X_2), i.e., the provision of material with textbooks against the research sample

O_1 : Measuring the competence of science literacy and the character of Pancasila class students Experiments before treatment (given pre-test)

O_2 : Re-measure science literacy competence and student character Pancasila experimental class after treatment (given post-test)

O_3 : Measuring the competence of science literacy and the character of Pancasila class students control before treatment (given pre-test)

O_4: Re-measure science literacy competence and student character Pancasila control class after treatment (administered post-test)

Figure 1. Cover of PRISMA E-Module

The e-module used in this study is a STEAM-based e-module developed by Utaminingsih [40], namely the Prisma E-Module. This E-Module has been tested for validity by experts from several aspects of assessment, including content, construction, and language. Four experts validated every aspect of the assessment. The results of the content validity of the Prisma e-module have a validity value of 0.96 from the content aspect, a validity value of 0.94 from the construction aspect, and a validity value of 0.93 from the language aspect. The overall score of the e-aspect of the e-module is 0.94, in other words it meets the valid criteria and is suitable for use as a teaching resource for the experimental class. The Prism E-Module used, the cover of which is presented in Figure 1.

The e-module was given six meetings. The implementation aimed to study the problem-solving indicators that students must master in each meeting. A list of activities for each meeting is illustrated in Table 2.

Table 2. List of Activities for Each Meeting

Meeting	Problem-Solving Indicator	Topics and Activities
I	*Observe and evaluate situations to define problems.* *Frame questions, make predictions, and design data collection and analysis strategies.*	Blood circulation Blood circulation system Differences between Arteries and Veins *Playing Video 1 and 2 (Human Blood Circulation System)*
II	*Frame questions, make predictions, and design data collection and analysis strategies.* *Identify and analyze the data or information's patterns, trends, and relationships.*	*Heart* *Heart Section, Size And Location* *Heart Function* *Video Playback 3 (Heart) and 4 (Heart and Circulatory)*
III	*Identify and analyze the data or information's patterns, trends, and relationships.* *Based on analysis of the data or information, generate options and use evidence to build a case for the best response*	*Heart* *Heart Disease and How to Keep Your Heart Healthy* *Video Playback 4 (How to Maintain Circulatory Organs) and Video 5 (How to Keep Your Heart Healthy)*
IV	*Identify opportunities for innovation and collaboration.* *Evaluate the available tools, including technology, and select one to address the problem.*	*Technology for the heart* *Vein*
V	*Identify opportunities for innovation and collaboration.* *Persist in solving challenging problems, adapting strategies and approaches as needed.*	*Lung* *Video Playback 6* *Creating Mind-Mapping*
VI	All indicators of problem-solving	Reviewing All Materials, Playing all videos and Practice Questions

The control and experiment groups were administered a post-test following the learning process. The purpose of providing a post-test was to analyze the influence of the e-module on improving the ability to solve problems in both groups in the context of learning human circulation. Differences in post-test results in both groups were compared and between pre-test and post-test results in each group.

T-Test Analysis

The analysis test was carried out with the help of the SPPS 25 Program. The Independent Sample t-test was conducted to determine the significant difference between the post-test results in the experimental and control groups. A considerable difference can be seen in the value of Sig. (2-tail) provided that if the value of Sig. (2-tail) is <0.05, then H_0 (no effect on the use of e-modules) is rejected, and H_a (there is an effect of the use of e-modules) is accepted.

Improvement Analysis

The next stage is carried out with the N-Gain test to determine the increased value of each indicator studied. In addition to knowing the improvement of each indicator, it is also used to analyze the difference in improvement from the experimental and control groups. N-Gain Equation Wahab et al. [41] used in Equation 2.

$$\mathrm{N-Gain} = \frac{\mathrm{Tpos - Tpre}}{\mathrm{Tmaks - Tpre}} \ldots\ldots\ldots\ldots\ldots \text{(Eq.2)}$$

Description: Tpos as average posttest score; Tpre as Pre-test average score; T_{max} as Ideal maximum score. The N-Gain score obtained by the equation can be analyzed for categories using the gain score interpretation table presented in Table 3.

Table 3. N-Gain Score Categories ⟨**g**⟩

Value ⟨g⟩	**Category**
⟨g⟩ > 0.7	High
0.3 ≤ ≤ 0.7⟨g⟩	Medium
⟨g⟩ < 0.3	Low

Results

Normality Test Results

Normality tests analyzed the data of the students' pre-test and post-test results to determine whether the data results were normally distributed or not. The results of the normality test of the pretest-posttest of problem-solving ability are presented in Table 4.

Table 4. Results of Problem-solving Normality Test (Shapiro-Wilk)

Class	**df**	**Sig. (2-tailed)**
Pre-test Experiment	53	0.862
Post-test Experiment	53	0.522
Pre-test Control	49	0.10
Post-test Control	49	0.263

Table 4 demonstrated that the data were normally distributed, as the Sig. (2-tailed) for all groups exceeded 0.05, thereby permitting the application of parametric statistical analysis. Subsequently, a hypothesis test was conducted using an Independent Sample t-test to determine the differences in enhancing problem-solving competence in the experimental and control groups. The Independent Sample t-test yielded obtained a Sig.

(2-tailed) value of 0.000, leading to the rejection of the null H_0, and the acceptance of the H_a. These findings indicate a statistically significant difference in the average score between the experimental class and the control groups. Thus, it was concluded that using the Prisma e-module in the experimental class had a significant effect, supporting the improvement of students' problem-solving competence.

Implementation in the Experimental Group

The experimental group was given a pretest before being given material using e-modules. During six meetings, students learned the topic of human blood circulation using the Prisma e-module. The posttest was conducted after students finished learning using the Prisma e-module. Complete data on the pretest-posttest results and the problem-solving N-Gain test is presented in Table 5 and Figure 2.

Table 5. Results of Score Acquisition and Improvement of Problem-Solving Ability

	Indicator of Problem-Solving	**Value**	
		Pretest	**Posttest**
A	Observe and evaluate situations to define problems.	43	83
B	Frame questions, make predictions, and design data collection and analysis strategies.	47	87
C	Identify and analyze the data or information's patterns, trends, and relationships.	45	79
D	Based on the data or information analysis, options are generated, and evidence is used to build a case for the best response.	46	80
E	Identify opportunities for innovation and collaboration.	29	81
F	Evaluate the available tools, including technology, and select one to address the problem.	38	82
G	Persist in solving challenging problems and adapting strategies and approaches as needed.	24	72

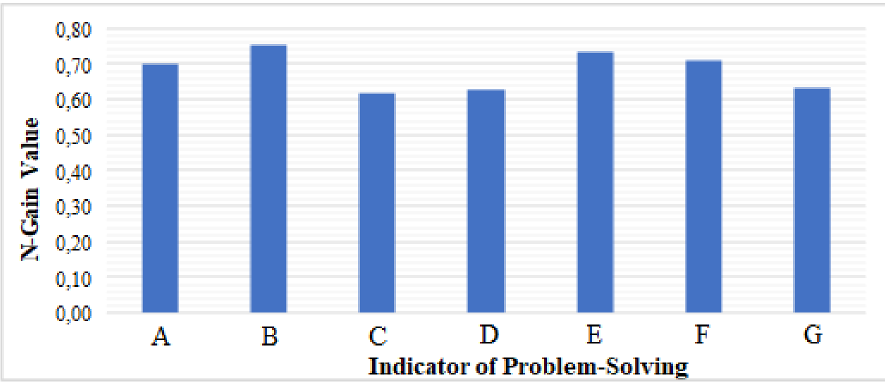

Figure 2. N-Gain Problem-Solving Ability of Experimental Group (A: Observe and evaluate situations, B: Frame questions, make predictions, and design data, C: Identify and analyze patterns, trends, and relationships, D: Analysis of the data, generate options and use evidence, E: Identify opportunities for innovation and collaboration, F: Evaluate the available tools, including technology and address the problem, G: Persist in solving challenging problems and adapting strategies)

Table 5 and Figure 2 demonstrated an increase in score acquisition from the pretest to the posttest in all indicators. Although not all indicators of problem-solving ability have improved in the "high" criterion, four out of seven indicators had enhanced with the "high" criterion. These criteria were in criteria A, B, E, and F. Overall, the increase in student scores based on calculations using the N-Gain formula in the experimental group was 0.68. Although it had not yet met the "high" criterion, this value was close to the "high" criterion, although it is still at the "medium" level, which is less than a value of 0.02 to reach the "high" criterion. The results indicated that the Prisma e-module could improve fifth-grade students' problem-solving ability at Supriyadi Elementary School Semarang.

Implementation in the Control Group

Teaching and learning activities in the control group were conducted four times. The researcher facilitated the knowledge transfer process using the Bupena Book. Similar to the experimental group, students were given a pretest before starting learning and then a posttest to assess the extent of improvement in their problem-solving abilities made before and after being given material using the Bupena textbook. The results of the pretest and posttest and the improvement in the problem-solving competence of the control group are presented in Table 6 and Figure 3.

Table 6. Value Each Indicator from the Control Group

Indicator of Problem-Solving		Value	
		Pretest	Posttest
A	Observe and evaluate situations to define problems.	43	58
B	Frame questions, make predictions, and design data collection and analysis strategies.	47	61
C	Identify and analyze the data or information's patterns, trends, and relationships.	45	63
D	Based on the data or information analysis, options are generated, and evidence is used to build a case for the best response.	35	54
	Identify opportunities for innovation and collaboration.	40	61
F	Evaluate the available tools, including technology, and select one to address the problem.	38	53
G	Persist in solving challenging problems and adapting strategies and approaches as needed.	25	43

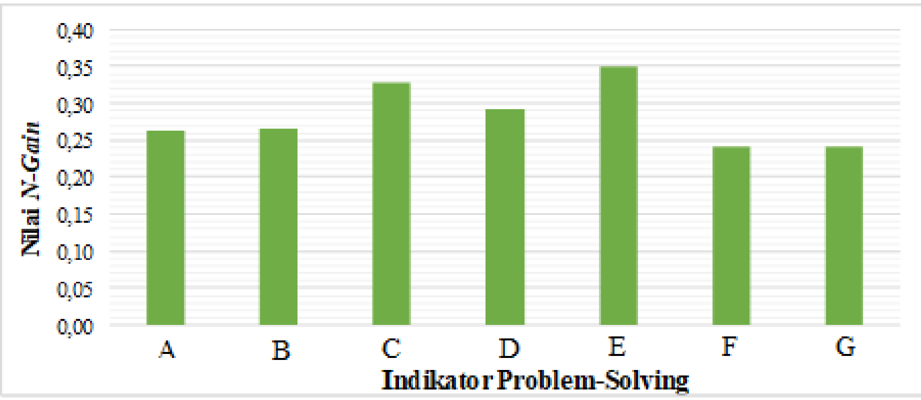

Figure 3. N-Gain Problem-Solving Ability of Control Group (A: Observe and evaluate situations, B: Frame questions, make predictions, and design data, C: Identify and analyze patterns, trends, and relationships, D: Analysis of the data, generate options and use evidence, E: Identify opportunities for innovation and collaboration, F: Evaluate the available tools, including technology and address the problem, G: Persist in solving challenging problems and adapting strategies)

Based on Table 6 and Figure 3, it could be concluded that there was an increase in problem-solving ability in human circulatory learning within the "Bupena" textbook in the control group. However, the increase was not statistically significant, amounting to only 0.28, with the "low" range. The increase was relatively modest compared to the increase in the experimental group.

Differences Between Experimental Group and Control Group

The learning process utilizing the Prisma e-module, compared to the textbooks used by the school, produced distinct outcomes in problem-solving performance. These differences were evident from the accumulation of test results of the students' problem-solving tests in Table 5 and Table 6. A more notable distinction was observed in the N-Gain values of the experimental and control groups, illustrated in Figure 4.

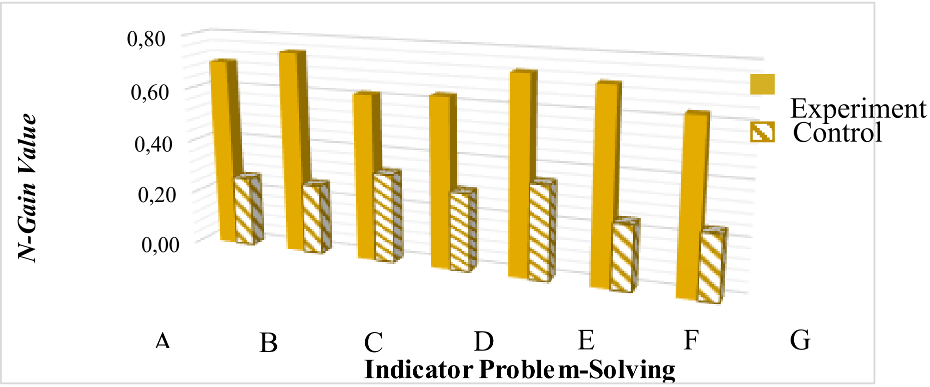

Figure 4. N-Gain Difference in Problem-solving Score (A: Observe and evaluate situations, B: Frame questions, make predictions, and design data, C: Identify and analyze patterns, trends, and relationships, D: Analysis of the data, generate options and use evidence, E: Identify opportunities for innovation and collaboration, F: Evaluate the available tools, including technology and address the problem, G: Persist in solving challenging problems and adapting strategies)

The significant difference in the achievement of problem-solving skills between the two groups indicated that the students in the experimental group could answer the questions given accurately and clearly. In contrast, the control group had not mastered the problem-solving ability. The results also demonstrated that the Prisma e-module positively enhanced problem-solving skills, making it effective and efficient for learning.

Discussion

Enhancement of Problem-Solving Ability Through STEAM-Based-E-Modul

Implementing STEAM-based e-modules significantly enhanced students' problem-solving abilities compared to traditional teaching methods using printed textbooks. An N-Gain value of 0.68 was observed in the experimental group, categorized as high, whereas the control group achieved a value of 0.28, classified as low. Such outcomes underscored the effectiveness of integrating educational technology to strengthen 21st-century competencies, particularly in complex subjects such as the human circulatory system.

The findings align with [28] research demonstrated that the STEAM approach effectively enhanced students' critical reasoning skills. The incorporation of artistic and technological elements within STEAM facilitated the development of innovative solutions to problems, as evidenced by the increased problem-solving scores in the experimental group. Additionally, [42] affirmed that interactive digital modules deepened students' conceptual understanding and improved their ability to apply scientific knowledge in real-world contexts. Zakarsih [35] findings further supported these results, revealing that traditional teaching methods, although still predominant in Indonesia, were less effective in enhancing student competencies than technology-based methods.

A significant difference between the experimental and control groups indicated that the PRISMA e-module possessed distinct advantages, overcoming the limitations inherent in traditional methods. Such evidence supported Suprihati [43] assertion that educational technology can address geographical and resource constraints frequently faced by schools in Indonesia. Consequently, the present study reinforced previous findings and contributed additional empirical evidence regarding the effectiveness of STEAM-based e-modules in primary science education.

Theoretically, the study reinforced the STEAM-based learning model as an interdisciplinary approach integrating technology, arts, and sciences [44]. This perspective is aligned with the constructivist theories proposed by Piaget and Vygotsky, emphasizing the importance of active student interaction with the learning environment to construct knowledge [45,46]. The PRISMA e-module, characterized by its interactive and multimodal nature, supported this constructivist process by providing various resources accessible to students independently and collaboratively.

In practical terms, the results demonstrated that using the PRISMA e-module enabled teachers to implement more dynamic and adaptive teaching methods. Educators were able to tailor learning materials to meet students' diverse needs and abilities, facilitating more practical discussions and collaborations [47]. Furthermore, the e-module supported the development of 21st-century competencies, such as problem-solving, creativity, and critical thinking skills, which were increasingly vital in addressing global challenges in the digital era [24].

Significant improvements in indicators such as "identifying opportunities for innovation and collaboration" and "evaluating available tools to solve problems" suggested that the PRISMA e-module effectively encouraged students to engage in creative and critical thinking. This observation was consistent with [48,49] findings indicated that educational technology could enhance student engagement and motivation in the learning process. However, specific indicators, such as "adapting strategies to solve challenging problems," exhibited lower values [50]. The discrepancy may have been attributed to students' limited experience using technology as a learning tool [51], highlighting the need for further training for both teachers and students [52].

Persistent challenges related to technology accessibility in certain regions were revealed despite the effectiveness of the PRISMA e-module in enhancing problem-solving skills. Such findings align with [53], which identified the digital divide as a significant barrier to implementing educational technology in various parts of Indonesia [8]. Therefore, efforts to improve technological infrastructure and provide comprehensive training for teachers were essential to maximize the potential of STEAM-based e-modules [44].

Relevance to SDG 4: Quality Education

The integration of STEAM-based e-modules significantly contributed to the attainment of Sustainable Development Goal 4 (SDG 4), which aimed to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all [54]. By implementing the PRISMA e-module, the study addressed several key targets of SDG 4, particularly those related to enhancing learning outcomes and fostering inclusive education. The interactive and multimodal nature of the e-modules facilitates personalized learning experiences, catering to diverse student needs and learning styles [55]. This approach improves academic performance and promotes equity by providing equal access to quality educational resources [56], irrespective of students' geographical and socio-economic backgrounds [57].

Furthermore, enhancing problem-solving skills through STEAM-based e-modules is aligned to develop critical thinking and creativity, essential competencies for the 21st century [58]. Enabling students in hands-on, experiential learning fostered a deeper understanding of complex scientific concepts, improving overall educational quality [59]. Additionally, technology in education addresses barriers to learning by offering flexible and scalable solutions [60], that can be adapted to various educational settings, thereby supporting lifelong learning [61].

The study's findings underscored the importance of teacher training and professional development in effectively using educational technology [62]. Equipping educators with the necessary skills to implement STEAM-based e-modules promoted sustainable educational practices that could be maintained and expanded over time [63]. Emphasizing capacity building proved crucial for achieving long-term educational improvements and ensuring that quality education remains accessible to all students [64].

Moreover, the research highlighted the role of educational technology in bridging the digital divide, a significant challenge in many regions [65]. Demonstrating the effectiveness of STEAM-based e-modules in enhancing learning outcomes provided evidence for policymakers to invest in technological infrastructure and resources [66]. Such investments were essential for creating an equitable educational environment where all students have the opportunity to succeed [67].

In conclusion, the implementation of STEAM-based e-modules not only advanced the specific educational objectives of the study but also made meaningful contributions to the broader goals of SDG 4 [68]. The research supported the global agenda of fostering lifelong learning and preparing students to thrive in an increasingly complex [9] and interconnected world by promoting inclusive, equitable, and quality education through innovative technological solutions [8].

Practical Implications for Educators and Policymakers

The study provided significant practical implications for educators and policymakers, particularly in enhancing educational quality through integrating technology [69]. For educators, the research emphasizes the importance of adopting STEAM-based learning models, specifically through e-modules, to foster deeper engagement and improve student problem-solving abilities [21]. Teachers were encouraged to embrace technology as a dynamic tool to enhance learning experiences, moving beyond traditional teaching methods that rely heavily on printed textbooks [27]. The results highlighted the need for educators to develop skills in creating and using interactive and multimodal learning resources that cater to diverse learning styles and abilities [70].

Moreover, the findings indicated that teachers required comprehensive professional development and training to integrate STEAM-based e-modules into their teaching practices effectively [71]. Such training should focus on the technical aspects of digital tools and the pedagogical strategies that enable effective implementation [70]. Professional development programs must equip teachers with the knowledge and skills to adapt instructional materials to meet students' varied needs and to foster a collaborative, inquiry-based learning environment [57]. This would enable teachers to facilitate better creative thinking, critical reasoning, and problem-solving skills key competencies for the 21st century through the strategic use of technology [72].

In addition to teacher training, the research underscored the significance of providing adequate resources and support for teachers to implement these innovative teaching methods [73]. For example, access to digital devices, stable internet connections, and user-friendly learning platforms are essential for implementing classroom e-modules [74]. Educational technology should be seen as something other than a supplementary resource but as an integral part of the curriculum that enhances teaching and learning outcomes [35]. Thus, the study suggested that educational institutions must invest in infrastructure to ensure equitable access to digital learning tools for all students, regardless of their geographic location or socioeconomic status [75].

For policymakers, the findings provided explicit recommendations for creating and implementing policies that support integrating educational technology in schools [76]. Policymakers were encouraged to recognize that digital tools, such as STEAM-based e-modules [66], could bridge the educational divide by providing students in underserved areas with access to high-quality learning resources [75]. This was particularly important in Indonesia, where educational infrastructure and resource disparities are prevalent, especially in rural areas. The research emphasizes the need for policies that ensure schools, particularly those in remote or disadvantaged regions, are equipped with the necessary technology, including computers, tablets, and reliable internet access [77].

Policymakers were also urged to consider the implementation of nationwide [66] or regional programs that promote technological literacy among educators and students [78]. Such programs should enhance teachers' digital competence and ensure students have the necessary skills to succeed in an increasingly digital world [79]. Further, the study recommended that policymakers incentivize educational institutions to incorporate innovative teaching methods, such as STEAM-based modules, into their curricula [66]. This would modernize the educational system and ensure students acquire the skills and knowledge required to thrive in the 21st century [61].

Conclusion

The study demonstrated that implementing STEAM-based e-modules significantly enhanced the problem-solving skills of fifth-grade students in science, with the experimental group achieving an N-Gain score of 0.68, which was substantially higher than the 0.28 score observed in the control group. The findings underscore the effectiveness of integrating digital tools with an interdisciplinary approach to foster critical thinking, creativity, and analytical skills, particularly in complex topics such as the human circulatory system. By providing an interactive and multimodal learning experience, the e-modules directly contributed to advancing the goals of Sustainable Development Goal 4 (SDG 4), which focuses on promoting equitable and quality education. While some problem-solving indicators showed moderate progress, the study highlighted the need for enhanced teacher training and improved technological infrastructure. Addressing these areas is crucial to fully realizing the potential of digital education tools and ensuring their effective integration. The research also affirmed the transformative potential of STEAM-based e-modules as an innovative and scalable model for improving primary education, offering a promising solution to global educational challenges and fostering a more inclusive learning environment.

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References

1. Su, J.; Zhong, Y. Artificial Intelligence (AI) in Early Childhood Education: Curriculum Design and Future Directions. *Comput. Educ. Artif. Intell.* **2022**, *3*, 100072, doi:10.1016/j.caeai.2022.100072.
2. Karsam; Widiana, M.E.; Widyastuty, A.A.S.A.; Hidayati, K. PRESERVATION, STANDARDIZATION AND INFORMATION TECHNOLOGY 4.0 OF TRADITIONAL GEDOG TUBAN BATIK TO BE COMPETITIVE IN MARKETING DURING COVID-19. *Theor. Pract. Res. Econ. Fields* **2022**, *13*, 72 – 85, doi:10.14505/tpref.v13.1(25).06.
3. Gladden, M.E. Who Will Be the Members of Society 5.0? Towards an Anthropology of Technologically Posthumanized Future Societies. *Soc. Sci.* **2019**, *8*, doi:10.3390/socsci8050148.
4. Su, J.; Ng, D.T.K.; Chu, S.K.W. Artificial Intelligence (AI) Literacy in Early Childhood Education: The

Challenges and Opportunities. *Comput. Educ. Artif. Intell.* **2023**, *4*, 100124, doi:10.1016/j.caeai.2023.100124.
5. Chen, X.; Xie, H.; Hwang, G.J. A Multi-Perspective Study on Artificial Intelligence in Education: Grants, Conferences, Journals, Software Tools, Institutions, and Researchers. *Comput. Educ. Artif. Intell.* **2020**, *1*, 100005, doi:10.1016/j.caeai.2020.100005.
6. Dai, C.P.; Ke, F. Educational Applications of Artificial Intelligence in Simulation-Based Learning: A Systematic Mapping Review. *Comput. Educ. Artif. Intell.* **2022**, *3*, 100087, doi:10.1016/j.caeai.2022.100087.
7. Yang, W. Artificial Intelligence Education for Young Children: Why, What, and How in Curriculum Design and Implementation. *Comput. Educ. Artif. Intell.* **2022**, *3*, 100061, doi:10.1016/j.caeai.2022.100061.
8. Rizki, I.A.; Sunarti, T.; Salsabila, N.F. A Case Study of How Digital Competencies Affect Pre-Service Physics Teachers' Professional Growth: Realizing SDG 4. In Proceedings of the E3S Web of Conferences; N., S., B.K., P., M., S., H.P.A., T., M., A.G., S., A., Eds.; EDP Sciences: School of Education, Victoria University of Wellington, Wellington, New Zealand, 2024; Vol. 513.
9. Yingi, E.; Hlungwani, P.M.; Nyagadza, B. The Fourth Industrial Revolution (4IR) in the Heart of the SDG Agenda: The Role of Education in Zimbabwe. *Africa Rev.* **2022**, *14*, 213–229, doi:10.1163/09744061-01402001.
10. Ampadu, E.; Chechan, B. Swedish Students' Problem-Solving Perceptions and Its Implications for Teacher Training and Development. In Proceedings of the Proceedings - Frontiers in Education Conference, FIE; Institute of Electrical and Electronics Engineers Inc.: Royal Institite of Technology-Kth, Department of Learning, Stockholm, Sweden, 2022; Vol. 2022-Octob.
11. Utaminingsih, E.S.; Ramadhani, M.H.; Puspita, M.A. Fostering Superior Characters : Development of Innovative Instruments for Critical Reasoning and Independent Character in the Realm of Science Topic. *J. Penelit. Pendidik. IPA* **2024**, *10*, 4650–4661, doi:10.29303/jppipa.v10i8.7053.
12. Wang, K.; Dang, X.; Bai, J. A Multi-Scale Evaluation Model of Sustainable Development Goal 11.7 for Problem-Solving at Different Levels. *Land* **2024**, *13*, doi:10.3390/land13111750.
13. Suryani, A.; March, S.; Fleer, M.; Rai, P. Contributing to SDGs Through Conceptual PlayWorlds: Changing the STEM Story for Children, Families and Teachers. In *International Perspectives on Early Childhood Education and Development*; Springer Science and Business Media B.V.: Monash University, Melbourne, VIC, Australia, 2024; Vol. 42, pp. 59–70 ISBN 24688746 (ISSN).
14. Vásquez, C.; Piñeiro, J.L.; García-Alonso, I. What Challenges Does the 21st Century Impose on the Knowledge of Primary School Teachers Who Teach Mathematics? An Analysis from a Latin American Perspective. *Mathematics* **2022**, *10*, doi:10.3390/math10030391.
15. Utaminingsih, E.S. Social Science Learning in Primary School Responding to The Challenges of 21st Century Education. *Edueksos J. Pendidik. Sos. dan Ekon.* **2023**, *XII*, 270–282.
16. Azizah, N.; Suryanti, S.; Suprapto, N. Apollo and Comet Media Design to Practice Science Literacy for Elementary School Students. *AL-ISHLAH J. Pendidik.* **2022**, *14*, 2019–2030, doi:10.35445/alishlah.v14i2.2146.
17. Amaringga, N.G.; Amin, M.; Irawati, M.H. The Effect of Problem-Based Learning Module Containing Research Result to Improve Students' Scientific Literacy. *AIP Conf. Proc.* **2021**, *2330*, doi:10.1063/5.0043529.
18. Wasiluk, T.; So- Osman, C.; van den Burg, P.; Herczenik, E.; Al-Riyami, A.Z. The ISBT E-Learning Module in Transfusion Reaction: An Initiative for a Global Outreach. *Transfus. Apher. Sci.* **2022**, 62, 103633, doi:10.1016/j.transci.2022.103633.
19. Seruni, R.; Munawaroh, S.; Kurniadewi, F.; Nurjayadi, M. Implementation of E-Module Flip PDF Professional to Improve Students' Critical Thinking Skills through Problem Based Learning. *J. Phys. Conf. Ser.* **2020**, *1521*, 8–13, doi:10.1088/1742-6596/1521/4/042085.
20. Utaminingsih, E.S.; Ellianawati, E.; Sumartiningsih, S.; Puspita, M.A. STEAM Education. *J. Ilm. Profesi Pendidik.* **2023**, *8*, 1605–1612.
21. Quigley, C.F.; Herro, D.; King, E.; Plank, H. STEAM Designed and Enacted: Understanding the Process of Design and Implementation of STEAM Curriculum in an Elementary School. *J. Sci. Educ. Technol.* **2020**, 29, 499–518, doi:10.1007/s10956-020-09832-w.
22. Baek, S.; Shin, H.; Kim, C.J. Development of a Climate Change SSIBL-STEAM Program Aligned to the National Curriculum for SSI Elementary School in Korea. *Asia-Pacific Sci. Educ.* **2022**, 8, 109–148, doi:10.1163/23641177-bja10047.
23. Utaminingsih, E.S.; Raharjo, T.J.; Ellianawati Development of an E-Module Based on STEAM on the Topic of Human Blood Circulation. *J. Penelit. Pendidik. IPA* **2023**, 9, 5333–5340,

doi:10.29303/jppipa.v9i7.3719.
24. Kusmaharti, D.; Yustitia, V. Self-Regulated Learning-Based Digital Module Development to Improve Students' Critical Thinking Skills. *Al-Jabar J. Pendidik. Mat.* **2022**, *13*, 211–220, doi:10.24042/ajpm.v13i1.12756.
25. Triwahyuningtyas, D.; Ningtyas, A.S.; Rahayu, S. The Problem-Based Learning e-Module of Planes Using Kvisoft Flipbook Maker for Elementary School Students. *J. Prima Edukasia* **2020**, *8*, 199–208, doi:10.21831/jpe.v8i2.34446.
26. Chen, W.; Tang, X.; Mou, T. Course Design and Teaching Practice in STEAM Education at Distance via an Interactive E-Learning Platform: A Case Study. *Asian Assoc. Open Univ. J.* **2019**, *14*, 122–133, doi:10.1108/AAOUJ-07-2019-0027.
27. Khikmiyah, R.; Rusijono, R.; Arianto, F. The Effect of STEAM-Robotics on Science Subjects on Students' Ability to Solve Problems. *AL-ISHLAH J. Pendidik.* **2021**, *13*, 3061–3070, doi:10.35445/alishlah.v13i3.694.
28. Utaminingsih, E.S.; Anwar, A.; Arbi, A.; Lala, C.; Salama, M.S.; Apriantoro, S.; Intania, B.Y.; Ihsandi, A. Enhancing Critical Reasoning Character in Pancasila Students : A STEAM Approach by E-Module PRISMA. *J. Penelit. Pendidik. IPA* **2024**, *10*, 7296–7305, doi:10.29303/jppipa.v10i10.7325.
29. Utaminingsih, E.S.; Raharjo, T.J.; Ellianawati, E. *Development of an E-Module Based on STEAM on the Topic of Human Blood Circulation*; 2023; Vol. 9;.
30. UZ, L.Z.; Haryono; Wardani, S. The Development of Chemical E-Module Based on Problem of Learning to Improve The Concept of Student Understanding Article Info. *Innov. J. Curric. Educ. Technol.* **2019**, *8*, 59–66.
31. Arianto, F.; Hanif, M. Evaluating Metacognitive Strategies and Self-Regulated Learning to Predict Primary School Students ' Self -Efficacy and Problem-Solving Skills in Science Learning. *J. Pedagog. Res.* **2024**, *8*, 301–319.
32. Eaton, A.C.; Delaney, S.; Schultz, M. Situating Sustainable Development within Secondary Chemistry Education via Systems Thinking: A Depth Study Approach. *J. Chem. Educ.* **2019**, *96*, 2968–2974, doi:10.1021/acs.jchemed.9b00266.
33. How, M.L.; Hung, W.L.D. Educing AI-Thinking in Science, Technology, Engineering, Arts, and Mathematics (STEAM) Education. *Educ. Sci.* **2019**, *9*, 1–41, doi:10.3390/educsci9030184.
34. Prinsip, J.; Matematika, P. Integration of Islam in Application-Based E-Modules (A Development Study in Facilitating Problem-Solving Capability). *J. Prinsip Pendidik. Mat. Vol.* **2023**, 6, 127–137.
35. Zarkasih, Z.; Diniya, D.; Permana, N.D.; Kirana, I. Development of Science E-Modules Based on Socio-Scientific Issues Integrated with The Quran Verses to Establish Pancasila Student Profiles. *J. Nat. Sci. Integr.* **2023**, *6*, 63, doi:10.24014/jnsi.v6i1.21855.
36. Rahmadana, A.; Agnesa, O.S. Deskripsi Implementasi Steam (Science, Technology, Enginering, Art, Mathematic) Dan Integrasi Aspek "Art" Steam Pada Pembelajaran Biologi SMA. *JOTE J. Teach. Educ.* **2022**, *4*, 190–201.
37. Astuti, B.; Purwanta, E.; Lestari, R.; Bhakti, C.P.; Anggela, E.; Herwin, H. The Effectiveness of Digital Module to Improve Career Planning of Junior High School Students. *World J. Educ. Technol. Curr. Issues* **2022**, *14*, 940–950, doi:10.18844/wjet.v14i3.7396.
38. Sugiyono *Metode Penelitian Kuantitatif, Kualitatif Dan R&D*; Alfabeta: Bandung, 2015;
39. Nalendra, A.R.A. *Statistika Seri Dasar Dengan SPSS*; 2021; ISBN 9786236068311.
40. Utaminingsih, E.S. Pengembangan E-Modul Berbasis STEAM Topik Peredaran Darah Manusia Untuk Meningkatkan Literasi Sains Dan Karakter Pelajar Pancasila, Universitas Negeri Semarang, 2023.
41. Wahab, A.; Junaedi, J.; Azhar, M. Efektivitas Pembelajaran Statistika Pendidikan Menggunakan Uji Peningkatan N-Gain Di PGMI. *J. Basicedu* **2021**, *5*, 1039–1045, doi:10.31004/basicedu.v5i2.845.
42. Sulaiman, M. E-Module Based on Blended Learning for Islamic Religious Education Learning. *Indones. Res. J. Educ.* **2023**, *7*, 104–120.
43. Suprihati; Utaminingsih, S.; Suad Implementation of Digital Literacy in the Learning Module in Class VI Primary School. **2022**, 2, 7–10.
44. Rusni, I.; Fitria, Y.; Ahmad, S.; Zen, Z. Development of E-Modules Oriented by A Science, Technology, Engineering, Art, and Mathematics (STEAM) Approach to Improve High Level Thinking Ability. *J. Penelit. Pendidik. IPA* **2023**, *9*, 7179–7188, doi:10.29303/jppipa.v9i9.5345.
45. Istuningsih, W.; Baedhowi; Sangka, K.B. The Use Of Electrinic Modules For Learning Effectiveness. *Ijere* **2018**, *03*, 75–85.
46. Hyun, C.C.; Tukiran, M.; Wijayanti, L.M.; Asbari, M.; Purwanto, A.; Santoso, P.B. Piaget versus Vygotsky: Implikasi Pendidikan Antara Persamaan Dan Perbedaan. *J. Eng. Manag. Sci. Res.* **2020**, *1*, 286–293.

47. Ilmi, R.; Arnawa, I.M.; Yerizon; Bakar, N.N. Development of an Android-Based for Math E-Module by Using Adobe Flash Professional CS6 for Grade X Students of Senior High School. *J. Phys. Conf. Ser.* **2021**, *1742*, 1–7, doi:10.1088/1742-6596/1742/1/012026.
48. Astalini, A.; Darmaji, D.; Kurniawan, D.A.; Chen, D. Students' Perceptions of Mathematical Physics E-Module on Multiple Integral Material. *J. Educ. Technol.* **2021**, *5*, 531, doi:10.23887/jet.v5i4.33600.
49. Dhillon, S.; Murray, N. An Investigation of EAP Teachers' Views and Experiences of E-Learning Technology. *Educ. Sci.* **2021**, *11*, 1–16, doi:10.3390/educsci11020054.
50. Fernández Herrero, J.; Gómez Donoso, F.; Roig Vila, R. The First Steps for Adapting an Artificial Intelligence Emotion Expression Recognition Software for Emotional Management in the Educational Context. *Br. J. Educ. Technol.* **2023**, *54*, 1939–1963, doi:10.1111/bjet.13326.
51. Hsu, H.P.; Wenting, Z.; Hughes, J.E. *Developing Elementary Students' Digital Literacy Through Augmented Reality Creation: Insights From a Longitudinal Analysis of Questionnaires, Interviews, and Projects*; 2019; Vol. 57; ISBN 0735633118.
52. Sakka, F.; Gura, A.; Latysheva, V.; Mamlenkova, E.; Kolosova, O. Solving Technological, Pedagogical, and Psychological Problems in Mobile Learning. *Int. J. Interact. Mob. Technol.* **2022**, *16*, 144 – 158, doi:10.3991/ijim.v16i02.26205.
53. Chauhan, S. A Meta-Analysis of the Impact of Technology on Learning Effectiveness of Elementary Students. *Comput. Educ.* **2017**, *105*, 14–30, doi:10.1016/j.compedu.2016.11.005.
54. Manikutty, G.; Prabha, P.; Unnithan, M.S.; Ayisha, E.A.; Sasidharan, S. An Explorative Case Study on Effects of a Makeathon for SDGs on Middle School Students Learning and Democratic Empowerment. In Proceedings of the IEEE Global Engineering Education Conference, EDUCON; IEEE Computer Society: Amrita Vishwa Vidyapeetham, AMMACHI Labs, Amritapuri, India, 2023; Vol. 2023-May.
55. Jesionkowska, J.; Wild, F.; Deval, Y. Active Learning Augmented Reality for STEAM Education—A Case Study. *Educ. Sci.* **2020**, *10*, 1–15, doi:10.3390/educsci10080198.
56. Kant, J.; Burckhard, S.; Meyers, R. Engaging High School Girls in Native American Culturally Responsive STEAM Activities. *J. STEM Educ. Innov. Res.* **2017**, *18*, 15–25.
57. Milara, I.S.; Pitkänen, K.; Laru, J.; Iwata, M.; Orduña, M.C.; Riekki, J. STEAM in Oulu: Scaffolding the Development of a Community of Practice for Local Educators around STEAM and Digital Fabrication. *Int. J. Child-Computer Interact.* **2020**, *26*, 1–14, doi:10.1016/j.ijcci.2020.100197.
58. Putri, S.U.; Taqiudin, A.A. Steam-PBL: Strategi Pengembangan Kemampuan Memecahkan Masalah Anak Usia Dini. *J. Obs. J. Pendidik. Anak Usia Dini* **2021**, 6, 856–867, doi:10.31004/obsesi.v6i2.1270.
59. Wang, W.; Seshaiyer, P. Engaging Students in Applied Mathematics Education and Research for Global Problem Solving. In *SEMA SIMAI Springer Series*; Springer Science and Business Media Deutschland GmbH: Department of Mathematical Sciences, George Mason University, Fairfax, VA, United States, 2021; Vol. 7, pp. 27–49 ISBN 21993041 (ISSN).
60. O'Sullivan, L.; Seabra, N.M. School in a Box in Low Resource Primary School in Mozambique: Practical Application of Zone of Proximal Development in Teacher Training with Mobile Technology. *Int. J. Mob. Blended Learn.* **2016**, *8*, 44–54, doi:10.4018/IJMBL.2016040104.
61. Hoang, A.-D.; Pham, H.-H.; Nguyen, Y.-C.; Nguyen, L.-K.-N.; Vuong, Q.-H.; Dam, M.Q.; Tran, T.; Nguyen, T.-T. Introducing a Tool to Gauge Curriculum Quality under Sustainable Development Goal 4: The Case of Primary Schools in Vietnam. *Int. Rev. Educ.* **2020**, 66, 457–485, doi:10.1007/s11159-020-09850-1.
62. Chin, C.K.; Munip, H.; Miyadera, R.; Thoe, N.K.; Ch'ng, Y.S.; Promsing, N. Promoting Education for Sustainable Development in Teacher Education Integrating Blended Learning and Digital Tools: An Evaluation with Exemplary Cases. *Eurasia J. Math. Sci. Technol. Educ.* **2019**, *15*, doi:10.29333/ejmste/99513.
63. Sá, P.; Silva, P.C.; Peixinho, J.; Figueiras, A.; Rodrigues, A. V Sustainability at Play: Educational Design Research for the Development of a Digital Educational Resource for Primary Education. *Soc. Sci.* **2023**, *12*, doi:10.3390/socsci12070407.
64. Sawamura, N. Universal Primary Education in Africa: Facets and Meanings. In *The Palgrave Handbook of African Education and Indigenous Knowledge*; Palgrave Macmillan: International Collaboration and Development Studies, Graduate School of Human Sciences, Osaka University, Suita, Japan, 2020; pp. 637–655 ISBN 978-303038277-3 (ISBN); 978-303038276-6 (ISBN).
65. Sentíes Maqueda, A.; Olais-Govea, J.M.; Cuellar-Reynaga, D.A.; Rosales Salas, E.J.; Torres Zafra, E.; Flores Sayavedra, Y.Y.; Aguilar-Mejía, J.R.; Reynaga-Peña, C.G. Application of RFID Technology to Create Inclusive Educational Resources. In Proceedings of the Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); M.,

A., C., S., Eds.; Springer Science and Business Media Deutschland GmbH: Tecnologico de Monterrey, Av. Eugenio Garza Sada 2501, NL, Monterrey, Mexico, 2023; Vol. 14021 LNCS, pp. 405–416.

66. Lu, S.-Y.; Wu, C.-L.; Huang, Y.-M. Evaluation of Disabled STEAM-Students' Education Learning Outcomes and Creativity under the UN Sustainable Development Goal: Project-Based Learning Oriented STEAM Curriculum with Micro:Bit. *Sustain.* **2022**, *14*, doi:10.3390/su14020679.
67. Sotos-Martínez, V.J.; Tortosa-Martínez, J.; Baena-Morales, S.; Ferriz-Valero, A. Boosting Student's Motivation through Gamification in Physical Education. *Behav. Sci. (Basel).* **2023**, *13*, doi:10.3390/bs13020165.
68. Bhaduri, I.; Aryamol, K.B.; Sahoo, B.L. Leveraging Technology for Multidisciplinary and Transdisciplinary Learning to Achieve Sustainable Development Goal 4: Quality Education. In *Studies in Big Data*; Springer Science and Business Media Deutschland GmbH: Department of English, Kristu Jayanti College, Bangalore, India, 2025; Vol. 158, pp. 127–142 ISBN 21976503 (ISSN).
69. Kioupi, V.; Voulvoulis, N. Assessing Learning Outcomes for Sustainability in Primary and Secondary Schools in the UK. In *Sustainable Development Goals Series*; Springer: Centre for Environmental Policy, Imperial College London, London, United Kingdom, 2022; Vol. Part F2743, pp. 221–246 ISBN 25233084 (ISSN).
70. Bertrand, M.G.; Namukasa, I.K. STEAM Education: Student Learning and Transferable Skills. *J. Res. Innov. Teach. Learn.* **2020**, *13*, 43–56, doi:10.1108/jrit-01-2020-0003.
71. Bilgiler, S.; Dergisi, E.A.; Monkeviciene, O.; Autukeviciene, B.; Kaminskiene, L.; Monkevicius, J. Impact of Innovative STEAM Education Practices on Teacher Professional Development and 3-6-Year-Old Children's Competence Development. *J. Soc. Stud. Educ. Res.* **2020**, *2020*, 1–27.
72. Lin, C.L.; Tsai, C.Y. The Effect of a Pedagogical STEAM Model on Students' Project Competence and Learning Motivation. *J. Sci. Educ. Technol.* **2021**, *30*, 112–124, doi:10.1007/s10956-020-09885-x.
73. Wahyuseptiana, Y.I.; Aje, D.P.; Widjanarko, P.; Childhood, E.; Teacher, E.; Study, E.; Thinking, C. STEAM Approach To Improving Critical Thinking Skills In Early Children. *Eur. J. Humanit. Educ. Adv. Available Online https//www.scholarzest.com Vol. 3 No. 09, Sept. 2022 ISSN 2660-5589 STEAM* **2022**, *3*, 26–31.
74. Kartini, D.; Widodo, A. Exploring Elementary Teachers', Students' Beliefs and Readiness toward STEAM Education. *Mimb. Sekol. Dasar* **2020**, *7*, 54–65, doi:10.17509/mimbar-sd.v7i1.22453.
75. Chan, C.K.Y. A Comprehensive AI Policy Education Framework for University Teaching and Learning. *Int. J. Educ. Technol. High. Educ.* **2023**, *20*, doi:10.1186/s41239-023-00408-3.
76. Wijatmoko, E.; Armawi, A.; Fathani, T.F. An Evaluation of a Special Government's Legal Structure for Alleviating Poverty: Role of Local Government in North Aceh, Indonesia. *J. Infrastructure, Policy Dev.* **2024**, *8*, doi:10.24294/jipd.v8i2.2630.
77. O'dea, X.; O'Dea, M. Is Artificial Intelligence Really the Next Big Thing in Learning and Teaching in Higher Education? A Conceptual Paper. *J. Univ. Teach. Learn. Pract.* **2023**, *20*, doi:10.53761/1.20.5.05.
78. Lazonder, A.W.; Walraven, A.; Gijlers, H.; Janssen, N. Computers & Education Longitudinal Assessment of Digital Literacy in Children : Findings from a Large Dutch Single-School Study. *Comput. Educ.* **2020**, *143*, 103681, doi:10.1016/j.compedu.2019.103681.
79. Silvhiany, S.; Mirizon, S.; Vianty, M.; Education, E.L. Digital Literacy Training for Teachers of English to Support 21st Century Learning. **2021**, *1*, 132–143.