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Research Article

Smart Card Media Based on Science Literacy in Nervous System Material for 11th Grade High School

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ABSTRACT

Purpose of the study: This study aims to develop Science Literacy-Based Smart Card Media on the nervous system material for 11th-grade science students and to test its validity, practicality, and effectiveness in improving students' science literacy skills.

Methodology: The study uses a Research and Development approach based on the 4-D model, which includes the stages of define, design, develop, and disseminate. The research subjects were 35 11th-grade science students at Budisatrya Private High School, Medan. Research instruments included interview guidelines, expert-validation questionnaires, teacher and student response questionnaires, and pretests and posttests. The data were analyzed descriptively using validity percentages, practicality, N-Gain, and a paired-samples t-test.

Main Findings: The research results show that the developed media received a media expert validation score of 96.42% and a material expert score of 89.06%, both of which fall into the very valid category. Practicality tests showed student responses of 95% and teacher responses of 98.14%, both categorized as very practical. Effectiveness tests showed an increase in average scores from 46 on the pretest to 90 on the posttest, with an N-Gain score of 0.81 (80.88%), categorized as high.

Novelty/Originality of this study: The novelty of this research lies in integrating PISA science literacy indicators into Smart Card media by presenting scientific phenomena, contextual case studies, data interpretation, and problem-solving activities on the nervous system. Science Literacy-Based Smart Card Media is declared valid, practical, and effective, making it suitable for use as an alternative Biology learning media to support the strengthening of students' science literacy.

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1. INTRODUCTION

The development of science and technology in the 21st century requires learners not only to master scientific concepts, but also to have critical thinking skills, problem-solving abilities, make decisions based on scientific evidence, and be able to apply knowledge in everyday life [1], [2]. This skill is known as scientific

literacy, which is the ability of a person to understand scientific phenomena, explain facts based on scientific concepts, critically evaluate information, and use scientific knowledge to solve various real-world problems. Scientific literacy is one of the important indicators of education quality because it helps shape human resources who can adapt to the development of science and technology [3], [4]. Therefore, learning biology in high school needs to be designed not just to focus on mastering the material, but also to help students develop their science literacy skills.

One of the biology topics that requires high-level thinking skills is the nervous system. This topic has a complex nature because it covers anatomical structures, the mechanism of nerve impulse transmission, coordination of the central and peripheral nervous systems, as well as its connection to various disorders in the human nervous system [5], [6]. The complexity of the material makes students often struggle to understand the connections between concepts, so learning tends to rely on memorization without deep understanding. This situation affects students' ability to interpret biological phenomena, connect concepts to real life, and apply knowledge to solve scientific problems. In fact, learning about the nervous system should be able to develop analytical skills, scientific reasoning, and science literacy through active, contextual, and meaningful learning experiences [7], [8].

Based on initial observations at Budisatrya Private High School in Medan, the biology learning process on the nervous system topic is still dominated by lectures, textbook use, and simple presentation media. Students tend to be passive information receivers, while opportunities for discussion, exploring concepts, or solving contextual problems are still limited. This condition results in relatively low learning motivation, less optimal learning activities, and students' science literacy skills not developing fully. Most students still have difficulty explaining scientific phenomena, interpreting biological information, and connecting nervous system concepts to events they encounter in everyday life. These findings show the need for more engaging, interactive learning media that can integrate science literacy indicators into the learning process.

One alternative learning media that can be developed is smart card media based on science literacy. Smart cards are visual learning tools designed in the form of cards containing concepts, images, illustrations, questions, case studies, or problem-solving challenges arranged systematically to make it easier for students to understand the material step by step. Integrating science literacy components into the cards allows students not only to learn biological concepts but also to analyze phenomena, interpret data, draw conclusions based on scientific evidence, and connect the material to everyday life. Besides boosting learning activities, smart cards can also encourage collaborative learning, increase motivation, strengthen concept retention, and create a more enjoyable learning experience.

Various studies show that the development of biology learning media, such as multimedia interactive tools, educational games, digital media, and even flashcards can boost students' motivation and learning outcomes. However, most of these studies still focus on improving cognitive aspects and concept mastery, while the development of media that explicitly integrates science literacy indicators is still relatively limited [9]. Moreover, the learning media that have been developed generally do not yet give students the opportunity to develop the ability to explain scientific phenomena, design solutions to contextual problems, and interpret scientific evidence as indicators of science literacy according to [10]. In the nervous system material, most research focuses more on using visual or multimedia tools to make it easier to understand the structure and function of the human nervous system. This approach has been proven to improve students' conceptual understanding, but it hasn't fully developed science literacy skills through activities like case analysis, data interpretation, or problem-solving related to nervous system disorders in real life. In fact, nervous system material is one of the biology topics with a high level of complexity, so it requires learning media that can systematically connect theoretical concepts with real-life phenomena [11].

Some previous studies have developed biology learning media, but they still show certain limitations. [12] creating effective biology smart cards that improve students' character scores on the immune system material. [13] developing smart card media for biology but to improve HOTS in students. [14] developing a biology smart card, but it doesn't cover the nervous system material and instead discusses cell material. Next, in the study that was reviewed by [15] by developing module media instead of smart card media, but this research was conducted on learning the excretory system and the coordination system to train students' science literacy. Based on this gap, the novelty of this research lies in the development of a Smart Card Media based on Science Literacy, specifically designed for nervous system material for 11th-grade science students at Budisatrya Private High School in Medan. Unlike typical learning card media that usually just present material summaries and practice questions, the media developed in this research integrates science literacy indicators into each card through the presentation of scientific phenomena, contextual case studies, data interpretation, scientific reasoning-based questions, and problem-solving activities. Therefore, this media not only serves as a tool to help understand concepts but also as a means to train critical thinking, scientific reasoning, and evidence-based decision-making skills.

In addition to producing valid, practical, and effective media products, this research also offers a model for developing learning media that systematically integrates science literacy competencies with the

characteristics of nervous system material. This development is expected to become an innovative alternative for biology learning that supports the implementation of the Merdeka Curriculum while also enriching studies on developing science literacy-based learning media for biology materials in high school.

2. RESEARCH METHOD

This study employed the Research and Development (R&D) method because it aimed to produce a product in the form of a Science Literacy-Based Smart Card Media on the nervous system topic and to examine the level of validity, practicality, and effectiveness of the developed media. The development model used was the 4-D model proposed by Thiagarajan et al. (1974), which consists of four stages: define, design, develop, and disseminate. This model was selected because it provides systematic stages for producing feasible and effective learning products [16]. The research was conducted at Senior high school Swasta Budisatrya Medan, located at Jalan Letda Sujono No. 166, Bandar Selamat, Medan Tembung District, Medan City, North Sumatra. The research subjects consisted of 35 students of Grade XI MIPA, selected using the purposive sampling technique, which is a sampling method based on specific considerations, such as students' characteristics, the suitability of the learning material, and recommendations from the subject teacher [17]. In addition to students, the study involved one Biology teacher as a respondent in the practicality test and three validators consisting of a material expert, media expert, and instrument expert.

The research procedure began with the define stage, which involved conducting initial analysis, learner characteristics analysis, concept analysis, task analysis, and learning objectives analysis through interviews with the Biology teacher and the distribution of needs analysis questionnaires to students. The design stage involved preparing the design of the Science Literacy-Based Smart Card Media, developing learning materials based on the Merdeka Curriculum, designing the media using the Canva application, and developing research instruments. Furthermore, in the develop stage, the product was validated by experts, revised based on expert suggestions, tested for practicality through teacher and student response questionnaires, and tested for effectiveness using pretest and posttest assessments. The final stage, disseminate, was carried out by implementing the media in Biology learning activities on the nervous system topic and introducing it to teachers as an alternative learning medium.

The research instruments consisted of test and non-test instruments. The non-test instruments included interview guidelines, needs analysis questionnaires, material expert validation sheets, media expert validation sheets, instrument expert validation sheets, teacher response questionnaires, and student response questionnaires. All questionnaires used a four-point Likert scale, consisting of a score of 4 (strongly agree), score 3 (agree), score 2 (disagree), and score 1 (strongly disagree). The test instrument consisted of pretest and posttest questions developed based on science literacy indicators. Before being implemented, all instruments were validated by experts to obtain content validity [18]. The research data consisted of qualitative and quantitative data. Qualitative data were obtained from interviews and validator suggestions, while quantitative data were obtained from expert validation results, teacher response questionnaires, student response questionnaires, and students' pretest and posttest scores.

Validity analysis is done using the following formula.

$$Percentage\ Validity = \frac{Score\ Obtained}{Score\ Maximum} \times 100\% \ldots (1)$$

Table 1. Media Validity Criteria

Percentage (%)	Criteria
80.00–100.00	Very Valid
60.00–79.99	Valid
50.00–59.99	Fairly Valid
< 50.00	Invalid

Next, the practicality analysis is done using the following formula.

$$Persentage\ Practicality = \frac{Score\ Obtained}{Score\ Maximum} \times 100\% \ldots (2)$$

Table 2. Media Practicality Criteria

Percentage (%)	Criteria
81–100	Very Practical
61–80	Practical
41–60	Fairly Practical
21–40	Less Practical
≤20	Not Practical

The effectiveness of the Smart Card Media based on Science Literacy was analyzed using Normalized Gain (N-Gain) to find out the improvement in students' learning outcomes after using the media. The formula used is as follows.

$$N - Gain = \frac{Score\ posttest - Score\ pretest}{Score\ maximum - Score\ pretest} \ldots (3)$$

Table 3. N-Gain Interpretation Criteria

N-Gain Score	Category
$g > 0.70$	High
$0.30 \leq g \leq 0.70$	Medium
$g < 0.30$	Low

To test the research hypothesis about the difference in learning outcomes before and after using the media, the pretest and posttest data are first tested for normality using the Shapiro–Wilk test. If the data is normally distributed, the analysis continues with the Paired Sample t-test. On the other hand, if the data is not normally distributed, the Wilcoxon Signed Rank Test is used. All statistical analyses are carried out using IBM SPSS Statistics version 26 with a significance level of 0.05 [9].

3. RESULTS AND DISCUSSION

This study produced a learning medium in the form of smart cards based on science literacy for the nervous system material in grade XI high school. These smart cards are designed to be used flexibly in classroom learning and can also be used as a support medium for independent learning. The smart cards are arranged in a concise and visual format, making it easier for students to understand the complex and abstract concepts of the nervous system. Using a concise, visual, and contextual medium can help students build conceptual understanding more easily and meaningfully. The development of this medium aims to improve science literacy, concept comprehension, and active student engagement through the presentation of contextual and practical material. The development process of the smart card medium follows the 4D model stages, namely Define, Design, Develop, and Disseminate, to ensure pedagogical suitability and the feasibility of the resulting medium.

This section presents a comprehensive analysis of the development process as well as the validity, practicality, and effectiveness of science literacy-based smart card media on the nervous system material. The discussion begins with an explanation of the results at each stage of the 4D development model, starting from the Define stage to Thiagarajan's Disseminate stage. Next, the effectiveness of the media is analyzed based on the results of pre-test and post-test assessments of students' science literacy skills, calculated using N-Gain scores to determine learning improvements. These analysis results form the basis for discussing each stage of developing the smart card media, starting from the definition stage. The development process aims to produce learning media that can integrate science literacy components so that students not only understand the concept of the nervous system but can also explain scientific phenomena, interpret data, and solve problems related to everyday life.

Define

The research results at the define stage showed that the development of smart card media based on science literacy started with a needs analysis, which included front-end analysis, learner analysis, concept analysis, task analysis, and learning objective analysis. This analysis provided an overview of the biology learning conditions at Budisatrya Medan Private High School as a basis for designing media that fits the students' needs and the demands of the Merdeka Curriculum. Based on front-end analysis, learning about the nervous system is still mostly dominated by the use of textbooks, worksheets, lectures, presentations, and educational videos. The learning process tends to be teacher-centered, so students memorize the material more than they understand the concepts deeply. This situation makes it difficult for students to connect nervous system concepts with real-life phenomena.

The analysis results of the students show that their initial abilities are quite varied. Besides that, students tend to get bored quickly when learning about the nervous system, which has a lot of abstract concepts. Most students are more interested in using learning media that are visual, concise, engaging, and interactive, making it easier for them to understand the material. The concept analysis resulted in a mapping of the main material to be included in smart card media, namely the structure of neurons, the mechanism of nerve impulses, the central nervous system, the peripheral nervous system, and various disorders of the nervous system. Meanwhile, task analysis shows that students are expected not only to understand these concepts but also to be able to connect them to everyday life applications as part of their science literacy skills.

Next, the analysis of learning objectives produces a formulation of competencies that refers to the Biology Learning Outcomes in the Merdeka Curriculum for 11th grade, namely that students are able to identify neuron structures, describe the mechanism of nerve impulses, explain voluntary and reflex movements, and describe the central and peripheral nervous systems. All of this analysis serves as the basis for designing smart card media based on science literacy that fits the learning needs. The needs analysis results show that the learning of the nervous system at SMA Swasta Budisatrya Medan is still focused on using conventional media, so the learning process tends to emphasize memorization. This condition indicates that students have not yet gained learning experiences that can build a deep conceptual understanding. This finding is in line with research [19] which states that the nervous system material is one of the biology topics that is difficult to understand because it has complex, abstract concepts and requires good conceptual thinking skills. The low interest in reading long texts is also one of the reasons for students' low understanding of this material.

The analysis of student characteristics shows that students prefer media with interesting visual displays, concise material presentation, and that allow interaction during the learning process. This finding aligns with the opinion [20] which explains that the use of visual media in active learning can boost students' attention, motivation, and engagement, making the learning process more effective. These characteristics show that developing smart cards is a suitable media alternative because it can present information in a simple, easy-to-understand, and attention-grabbing way for students. The analysis of concepts and tasks shows that learning about the nervous system is not only focused on mastering the concepts but also on the ability to connect those concepts to real-life situations. This aligns with the principles of science literacy, which emphasize students' ability to understand scientific concepts, explain phenomena based on scientific evidence, and apply knowledge to solve various everyday problems. The science literacy framework developed by [13] also emphasizes that the main goal of learning science is to shape students who can use scientific knowledge contextually in everyday life.

The learning objectives formulated based on the Merdeka Curriculum show that media development is not just focused on delivering material, but is also aimed at achieving the competencies expected in learning outcomes. Therefore, science literacy-based smart cards were designed so that each card not only contains information about the structure and function of the nervous system, but also includes examples of the concept applied in daily life as well as questions that encourage students to think critically. Thus, the results of the analysis at the definition stage prove that the development of science literacy-based smart cards aligns with the students' needs, the characteristics of nervous system material, and the direction of the Merdeka Curriculum policy, which emphasizes meaningful, contextual, and student-centered learning.

Design

The research results at the design stage showed that the science literacy-based smart card media was developed based on the needs analysis from the previous stage, so the media design was adjusted to the characteristics of the students, the nervous system material, and the learning outcomes for 11th grade Biology. The design was carried out systematically, focusing on presenting the material clearly, attractively, and understandably, while supporting student-centered learning. The design results show that the smart card media consist of several main components, namely the cover, user instructions, learning achievements, learning objectives, science literacy indicators, concept maps, and brief material about the nervous system. In addition, the media is also equipped with various supporting features, such as Did You Know which presents interesting scientific facts, a QR Code linked to learning videos, a Literacy Corner containing starter questions to train scientific thinking skills, practice questions for evaluation, as well as the author's biography placed on the card holder. All of these components are designed to support the achievement of students' science literacy competencies.

At this stage, a research instrument design is also produced, consisting of validation sheets for content experts, media experts, and language experts, questionnaires for teacher and student responses to measure the practicality of the media, as well as pre-test and post-test instruments used to measure the media's effectiveness in improving students' science literacy skills. The visual design results show that the smart card was created using the Canva app, paying attention to layout balance, color gradients, illustrations, QR code placement, and title frames to make it look appealing and easy to read. The media is printed in a 9 × 13 cm size on 200-gram paper with a thickness of about 2.3 mm, making it sturdy enough for repeated use. The choice of fonts—Noto Serif Ethiopic Condensed, Bree Serif, Times New Roman, and Bumblebee—as well as the use of black and blue text, was made to enhance readability and make it comfortable for learners to use the media.

The design stage is an important process in media development because it determines the quality of the product that will be used in learning. Research results show that the smart card design based on science literacy has been developed according to the characteristics of the students and the learning needs identified in the definition stage. This approach aligns with the 4-D development model, which emphasizes that learning products should be designed based on needs analysis so that they can address the problems found in the field [16]. The compilation of media components, which includes learning objectives, concept maps, concise materials, practice

questions, and various supporting features, shows that smart cards not only serve as a medium for delivering information but also as a tool that facilitates the development of students' science literacy. Features like Did You Know, QR Codes, and the Literacy Corner give students the chance to connect scientific concepts with real-world phenomena, explore digital learning resources, and develop critical thinking skills through contextual questions. This aligns with the framework of science literacy. [21] which emphasizes the importance of learning that can integrate scientific knowledge, thinking skills, and the application of concepts in everyday life.

Visual media design also becomes one of the important aspects that support the effectiveness of learning. The use of simple layouts, harmonious color combinations, relevant illustrations, and practical card sizes show that the media is designed with attention to the principles of learning design and visual communication. According to [22] In the Cognitive Theory of Multimedia Learning, presenting material that combines text, images, and visual elements in a balanced way can reduce students' cognitive load and improve concept understanding. Therefore, choosing illustrations, typography, and layout on smart cards is expected to help students grasp the abstract material of the nervous system.

In addition, the preparation of validation instruments, practicality questionnaires, as well as pre-tests and post-tests showed that the development process had been comprehensively designed to ensure the quality of the media before being implemented in learning. The existence of these instruments allows researchers to obtain data on the level of validity, practicality, and effectiveness of the media objectively. Thus, the results of the design stage show that the science literacy-based smart card has met the pedagogical, content, visual, and evaluation aspects so that it is feasible to proceed to the development stage as a learning medium that supports the improvement of students' science literacy in nervous system materials.

Develop

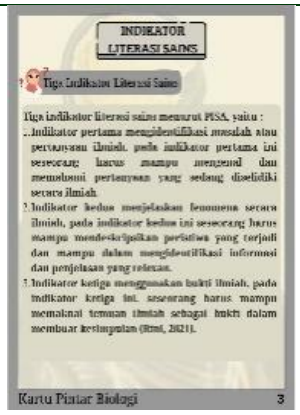
After the science literacy-based Smart Card learning media was developed in the design stage, the next stage was the develop stage. This stage aimed to assess the quality of the product through expert validation and practicality testing conducted by teachers and students. The development stage is an essential part of research and development because its results serve as the basis for determining the feasibility, practicality, and effectiveness of the Smart Card media before it is implemented on a wider scale. Feedback from the validators focused on aspects of content, presentation, visual appearance, and completeness of the material to ensure that the developed media was more suitable for students' characteristics and learning objectives.

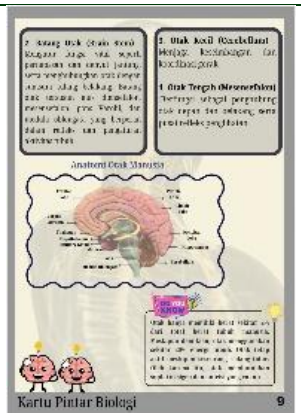
Several improvements were made, including emphasizing the text of the three science literacy indicators according to PISA and the core components of science literacy so that they could be more easily recognized by students. In addition, the Trigger Question section was changed into "Did You Know" and placed on the page discussing the nerve impulse material to make it more relevant to the learning content. Revisions were also made by adding illustrations of the classification of nerve cells, consisting of sensory neurons, motor neurons, and connector neurons, to clarify the concepts being studied. In terms of visual aspects, the layout of the human brain anatomy images was improved so that each anatomical part appeared clearer, more proportional, and easier to observe. Meanwhile, the material on nervous system disorders was simplified from six types to four types of disorders, accompanied by explanations of their causes, impacts, and treatments, making the information more concise, systematic, and easier to understand.

All suggestions and feedback from the validators were accommodated through the revision process, resulting in an improved Science Literacy-Based Smart Card Media in terms of content, appearance, and material presentation. The revised product then became the basis for proceeding to the final validation process before the media was tested on students.

Table 5. Comments from Media Validators and Material Validators

Suggestion	Before	After
In the section, the three science literacy indicators according to PISA, and the three core parts of the science literacy indicators need to have their font bolded.	None of the fonts on this page are bolded except for the main title.	The font on the three science literacy indicators according to PISA, and the three core parts of the science literacy indicators have been bolded.

Suggestion	Before	After
	 There's a starter question on the front page of the smart card.	 The trigger question has been changed to become part of the 'Did You Know' section, and it has been placed on the page that discusses nerve impulse material.
The trigger question is changed to just be part of the 'Did You Know' section, and placed on the page that discusses nerve impulse material.	 There are no images for the three parts of the neuron.	 The image has been added to the division of nerve cells.
Add an image of the division of nerve cells, which is divided into three parts: sensory neurons, motor neurons, and connector neurons.	 The human brain anatomy image is too cramped and the structure of its parts isn't clearly visible.	 The anatomy image has been repositioned and the anatomical structures are now clearly visible and neat.
In the picture of the human brain anatomy, the position needs to be adjusted so that the anatomical structures are clearly visible and neat.		

Suggestion	Before	After
	 Includes 6 explanations about human neurological disorders but has no explanation of causes and treatments for the diseases.	 Nervous system disorders are reduced to 4 disorders, and already include causes and effects, as well as treatments for disorders of the human nervous system.
The section on neurological disorders in humans would be better reduced to just 4 disorders, and include the causes and effects, as well as the treatment of disorders in the human nervous system.		

After the product revision process is completed based on feedback from the validators, the Science Literacy-Based Smart Card Media is then revalidated by media and content experts to determine the product's feasibility before it is implemented in the trial stage. The validation checks the feasibility of content, presentation, graphics, and the alignment of the material with learning objectives, ensuring that the media developed meets quality standards as a learning tool. The validation results from the media expert showed that the content feasibility aspect obtained a score of 46 out of a maximum score of 48, with a percentage of 96%, which was categorized as very valid. Meanwhile, the presentation aspect obtained a score of 8 out of a maximum score of 8, with a percentage of 100%, and was also categorized as very valid. Overall, the average validation result from the media expert reached 96.42%, indicating that the media has an attractive appearance, systematic material presentation, and a design that is appropriate to the characteristics of students.

The validation results from the material expert showed that the graphic aspect obtained a score of 29 out of a maximum score of 32, with a percentage of 91%, categorized as very valid. The material presentation aspect obtained a score of 28 out of a maximum score of 32, with a percentage of 88%, also categorized as very valid. The overall average validation result from the material expert reached 89.06%, indicating that the presented material was in accordance with the learning outcomes, had conceptual accuracy, and was systematically arranged so that it could be easily understood by students.

Based on the validation results from the media expert and material expert, the Science Literacy-Based Smart Card Media obtained an average validation percentage above 89%, with a very valid category. These results indicate that the media has met the feasibility criteria in terms of content, presentation, graphics, and material quality. Therefore, the media was declared suitable for use in the practicality test and effectiveness test during the learning process.

Table 6. Validation Results by Media Experts and Subject Matter Experts

Expert	Assessed Aspect	Number of Items	Score Obtained	Maximum Score	Percentage	Category
Media Expert	Content Feasibility	12	46	48	96%	Very Valid
	Presentation	2	8	8	100%	Very Valid
	Average Percentage (%)		27	28	96.42%	Very Valid
Subject Matter Expert	Graphics	8	29	32	91%	Very Valid
	Material Presentation	8	28	32	88%	Very Valid
	Average Percentage (%)		28.5	32	89.06%	Very Valid

After the Science Literacy-Based Smart Card Media was declared valid by the media expert and material expert, the next stage was conducting a practicality test to determine the level of ease of use of the media in the learning process. The practicality test involved one Biology teacher and 35 students of Grade XI MIPA as users of the media. The assessment was conducted using response questionnaires covering aspects of ease of use, media appearance, material presentation, readability, and the benefits of the media in supporting learning activities.

The results of the practicality test showed that the students' responses obtained an average percentage of 95%, which was categorized as very practical. These results indicate that students gave positive assessments of the media in terms of its appearance, ease of understanding the material, and ease of use during the learning process. The media was also considered capable of increasing students' interest in learning and helping them understand concepts related to the nervous system material more easily.

Meanwhile, the assessment results from the Biology teacher obtained a percentage of 98.14%, categorized as very practical. The teacher assessed that the Science Literacy-Based Smart Card Media was easy to use as a supporting learning medium, provided systematic material presentation, and helped teachers deliver learning materials in a more attractive, interactive, and efficient manner. Overall, the practicality test results showed that the Science Literacy-Based Smart Card Media received very positive responses from both teachers and students. The high practicality percentage indicates that the media has excellent usability, is easy to understand, visually attractive, and suitable for use as a learning medium for the nervous system topic.

Table 7. Practicality Test Results from Students and Teacher

Respondent	Number of Items	Score Obtained	Maximum Score	Percentage	Category
Students (n = 35)	12	45.6	48	95%	Very Practical
Teacher	27	26.5	27	98.14%	Very Practical

The development stage aims to produce learning media with high quality through a systematic process of validation and revision before being implemented in learning. Research results show that the Science Literacy Smart Card Media underwent several improvements based on feedback from validators, covering content, presentation, visual appearance, and material completeness. Revisions were made by bolding the science literacy indicators based on the PISA framework to make them easier for students to recognize, changing the Trigger Questions feature to a more contextual Did You Know, adding illustrations of different types of neurons, correcting the brain anatomy layout, and simplifying nervous system disorder materials into four types with explanations of causes, effects, and treatments. The findings show that the revision process is not just focused on the media's aesthetics, but also on improving the teaching quality so the material is easier for students to understand.

This finding aligns with research [23] which states that the quality of a developed product is determined by three main indicators, namely validity, practicality, and effectiveness. Validity is obtained through an evaluation process by experts to ensure that the content, presentation, and learning strategies are in line with the learning objectives. Likewise, according to [24], revisions based on validator feedback are an important stage in development research because they can improve the quality of the product before being used in real learning situations. Thus, the various revisions made to the Science Literacy-Based Smart Card Media show that the media development has followed systematic research and development principles, making the resulting product more representative of students' needs.

The validation results showed that the media received an average percentage of 96.42% from media experts and 89.06% from content experts, falling into the very valid category. The high validity scores indicate that the media meets aspects of content feasibility, presentation, graphics, and the suitability of the material with Biology learning outcomes. These results suggest that the material presented has accurate concepts, a well-

organized presentation, and visual displays that support the students' learning process. This finding is in line with previous research. [25] which explains that a learning media is considered valid if it meets the alignment between learning objectives, material characteristics, student characteristics, and media design. Besides that, research [26] also reported that learning media based on educational cards that achieved a validity level above 85% are considered feasible to use because they can present information systematically and make it easier for students to understand complex biology concepts.

From the aspect of material presentation, the high validation score shows that organizing the material in a concise form with illustrations, QR Codes, and the Did You Know feature can improve the quality of the media as a learning resource. According to [27] Through the Cognitive Theory of Multimedia Learning, presenting information using a combination of text, images, and multimedia will help learners build better mental representations compared to text-only presentations. Adding neuron illustrations and improving the positioning of brain anatomy images in the developed media is a form of applying the multimedia principle, which integrates visual and verbal elements, thereby reducing learners' cognitive load when studying the abstract nervous system material. Therefore, the very high validation results not only show the quality of the media content but also indicate that the visual design has supported a more effective learning process.

Besides being valid, the media that was developed also shows a very high level of practicality. The practicality test results reached 95% from students and 98.14% from teachers, falling into the very practical category. These findings show that the media is easy to use, attractive in appearance, easy to understand, and capable of increasing students' interest in learning. The high positive response from students indicates that the smart card media successfully meets the characteristics of today's learners who prefer visual, interactive, concise, and easily accessible media. These results are in line with research. [28] which found that learning media based on educational cards can increase learning motivation, student engagement, and create a more active learning atmosphere compared to the use of conventional media. Likewise, the research [29] reporting that science literacy-based media developed visually and contextually achieved a practicality level of over 90% because it is easy to use for both teachers and students.

The teacher's response of 98.14% shows that the media is not only convenient for students but also makes it easier for teachers to carry out the lessons. Teachers felt that the material presentation was systematic, the language was easy to understand, and supporting features like QR Codes and Did You Know could enrich the learning process. These findings support the opinion [30] which states that good learning media should be able to help teachers deliver material more efficiently, increase learning interaction, and optimize the achievement of learning objectives. Therefore, the high level of practicality obtained shows that Science Literacy-Based Smart Card Media has great potential to be applied in Biology learning, especially on the nervous system material. Which states that good learning media should be able to help teachers deliver material more efficiently, increase learning interaction, and optimize the achievement of learning objectives. Therefore, the high level of practicality obtained shows that Science Literacy-Based Smart Card Media has great potential to be applied in Biology learning, especially on the nervous system material.

Disseminate

The effectiveness test was carried out to find out how far the Science Literacy-Based Smart Card Media could improve students' science literacy skills on the nervous system material. The testing was done using a pretest–posttest design, which involves giving an initial test before learning with the media and a final test after the learning process is complete. The pretest and posttest results were then analyzed using Normalized Gain (N-Gain) to see the level of improvement in students' learning outcomes. The analysis results showed that the students' average pretest score was 46, while the average posttest score increased to 90. This improvement indicates a difference in students' science literacy skills before and after using the Science Literacy-Based Smart Card Media in the learning process.

Based on the N-Gain calculation results, a value of 0.81 was obtained with an improvement percentage of 80.88%, which falls into the high category. These results show that the developed media can provide a high improvement in students' science literacy skills. This increase indicates that presenting material with illustrations, scientific phenomena, contextual information (Did You Know), as well as science literacy-based activities helps students better understand the nervous system concepts. Overall, the effectiveness test results show that the Science Literacy-Based Smart Card Media is effective for teaching Biology on the nervous system topic. This is shown by the students' score improvements from the pretest to the posttest results and an N-Gain value in the high category, meaning the developed media meets the effectiveness criteria as a learning medium.

Table 8. Pre-Test and Post-Test Results of Scientific Literacy

Pre-Test	Post-Test	N-Gain	Percentage	Category
46	90	0.809	80.88%	High

The research results show that the Science Literacy-Based Smart Card Media that was developed meets the criteria of being very valid, very practical, and effective in improving students' science literacy skills on the nervous system material. The high level of media validity obtained from media experts (96.42%) and content experts (89.06%) indicates that the media has met the aspects of content feasibility, presentation, graphics, and alignment with learning outcomes. These results suggest that the development process using the 4-D model (Define, Design, Develop, Disseminate) is able to produce a learning product that is systematic and fits students' needs. According to [16], Each stage in the 4-D model aims to ensure that the product being developed has good quality through the process of needs analysis, design, validation, revision, and implementation. Therefore, the high validation score in this study indicates that the development process has been carried out optimally, resulting in media that is suitable for use in learning.

The findings of this study are in line with research [31] which states that science literacy-based learning media developed through expert validation received the category of very valid because it was able to integrate scientific concepts, real-life phenomena, as well as scientific thinking activities into a single learning medium. Likewise, research [32] found that learning media designed based on science literacy indicators have better content and presentation quality compared to conventional media because they can connect concepts with everyday life contexts. These results reinforce that the validity of media is not just determined by the accuracy of the material, but also by the media's ability to develop science literacy skills as recommended by the Programme for International Student Assessment (PISA) framework.

In addition to having a high level of validity, the developed media also received a very practical category, with responses from students at 95% and teachers at 98.14%. The high level of practicality shows that the media is easy to use, has an attractive appearance, is easy to understand, and can boost students' learning motivation. These results indicate that visual design, the use of illustrations, concise information presentation, and the Did You Know feature provide a more engaging learning experience compared to learning that only uses textbooks. According to [33], [34] In the Cognitive Theory of Multimedia Learning, a combination of text, images, illustrations, and contextual information can reduce the cognitive load on learners, making it easier for them to understand concepts. As a result, the media developed meets multimedia principles that can boost learners' attention and engagement during the learning process.

Those findings also align with research [35] who reported that learning media based on educational cards achieved a very high level of practicality because they are easy to use for both teachers and students. The research [36] It also shows that using interactive visual media can boost students' motivation and active participation during Biology lessons. The similarity of these results shows that the characteristics of visual-based media make it easier to understand abstract concepts, making learning more meaningful. The most important result of this study is the high effectiveness of the media in improving students' science literacy skills. The average pretest score of 46 increased to 90 in the posttest, with an N-Gain of 0.81, which falls into the high category. This result shows that using Science Literacy-Based Smart Cards significantly improves science literacy skills after the learning process. This improvement is largely due to the characteristics of the media, which include concept illustrations, scientific phenomena, problem-based activities, and contextual information that encourage students to connect Biology concepts with everyday life [37]-[42].

The results are in line with the report [43] which emphasizes that science literacy is not only about mastering concepts, but also the ability to explain scientific phenomena, evaluate evidence, interpret data, and make decisions based on scientific proof. Therefore, learning media that integrates all three of these competencies tend to provide a higher improvement in science literacy skills compared to learning that is focused solely on memorizing concepts. Research [44] It also explains that science literacy-based learning can improve critical thinking, scientific reasoning, and problem-solving skills because students actively construct knowledge through contextual learning experiences.

The findings of this study also support the results of the research [45] which found that science literacy-based media significantly improved students' ability to interpret scientific data and explain life phenomena. Similarly, research [46], [47] It shows that learning media based on educational cards lead to an improvement in learning outcomes with a high N-Gain category because students are more active in discussing, observing illustrations, and connecting concepts to real-life situations. The similarity of these results indicates that science literacy-based media has a tangible contribution to improving 21st-century competencies, especially critical thinking, scientific communication, and problem-solving skills.

The science Literacy-Based Smart Card Media not only meets product quality aspects in terms of validity and practicality, but also significantly improves students' science literacy skills. The novelty of this research lies in integrating PISA science literacy indicators into the smart card media through the presentation of nervous system illustrations, Did You Know contextual information, scientific phenomena, and analysis activities designed to train students to explain scientific phenomena, interpret data, and solve science-based problems. Thus, the developed media can be an innovative alternative in teaching Biology while also supporting the implementation of 21st-century learning focused on strengthening science literacy [48]-[51].

4. CONCLUSION

This study successfully developed Smart Card Media Based on Science Literacy for the nervous system material using the 4-D model, which was proven to meet the criteria of being very valid, very practical, and effective. Expert validation results indicated that the media is suitable for use in learning, while practicality tests showed that the media is easy to use and received very positive responses from both teachers and students. In addition, using the media was proven to significantly improve students' science literacy skills, as shown by the increase in pretest to posttest scores, high-category N-Gain values, and Paired Sample t-test results indicating significant differences before and after using the media. These findings suggest that the Science Literacy-Based Smart Card Media could be an alternative Biology learning tool that supports 21st-century learning by enhancing science literacy skills. However, this study is still limited to one school, one learning material, and measuring learning outcomes in the short term. Therefore, it is recommended that future research tests the media on a larger sample, applies it to other Biology or science topics, develops it in digital or interactive technology formats, and explores its effects on critical thinking, problem-solving, creativity, and long-term learning retention.

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AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Development of learning media, Writing – original draft preparation, and Writing – review and editing, R.A.A.; Supervision, Validation, Methodology, and Writing – review and editing, K.M. Both authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT

Prior to participation, each subject was provided with a detailed explanation of the study's objectives, procedures, potential risks, and benefits. All participants voluntarily agreed to participate and signed a written informed consent form. All images in this article have been authorized and are the property of the authors.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

REFERENCES

[1] T. Iskandar, M. Mesiono and M. Sit, "Strategies and challenges in teacher development: a comparative multisite study in indonesian higher education," *AL-ISHLAH: Jurnal Pendidikan,* vol. 17, no. 4, pp. 6510-6521, 2025, doi: 10.35445/alishlah.v17i4.7283

[2] P. P. K. P. Karmila, S. Rosamsi and Y. Ibrahim, "Peningkatan berpikir kritis melalui e-modul sistem saraf berbasis exe learning untuk pendidikan berkelanjutan [Improving critical thinking through a nervous system e-module based on exe learning for sustainable education]," *BIOSFER: Jurnal Biologi dan Pendidikan Biologi ,* vol. 10, no. 1, pp. 35-57, 2025, doi: 10.23969/biosfer.v10i1.35257

[3] R. N. Wijayanti and I. Isnawati, "Pengembangan media pembelajaran berbasis flipbook interaktif pada materi sistem saraf manusia untuk meningkatkan motivasi belajar siswa kelas xi sma [Development of interactive flipbook-based learning media on human nervous system material to boost learning motivation for 11th grade high school students]," *Berkala Ilmiah Pendidikan Biologi (BioEdu),* vol. 12, no. 2, pp. 298-310, 2023, doi: 10.26740/bioedu.v12i2.p298-310

[4] Z. Zulkifli, A. Lahmi, D. Dahlan and R. Hakim, "Mekanisme kerja otak dan sistem saraf: perspektif neurosains pendidikan Islam [How the brain and nervous system work: an islamic education neuroscience perspective]," *Menara Ilmu : Jurnal Penelitian dan Kajian Ilmiah,* vol. 19, no. 1, pp. 118-130, 2025. doi: 10.31869/mi.v19i1.6138.

[5] S. M. S. Meutia, N. Utami, R. Himayani and S. Rahmawati, "Central and peripheral nervous system," *Medical Profession Journal of Lampung,* vol. 11, no. 3, pp. 306-311, 2022. doi: 10.53089/medula.v11i3.189.

[6] A. P. W. Silaban and K. Manalu, "Development of a mindmap-based module to improve student learning outcomes in ecosystem biology learning material," *BIOINOVED: Jurnal Biologi-Inovasi Pendidikan,* vol. 6, no. 1, pp. 48-55, 2024. doi: 10.20527/bino.v6i1.18666.

[7] L. R. Rosalina and N. Nurdiani, "Meningkatkan kemampuan analisis peserta didik pada materi sistem saraf melalui pembelajaran blended learning berbasis TPACK [Improving students' analytical skills on nervous system material

through tpack-based blended learning]," *BIOSFER: Jurnal Biologi dan Pendidikan Biologi ,* vol. 8, no. 1, pp. 46-76, 2023, doi: 10.23969/biosfer.v8i1.4676.

[8] M. A. Nasution, N. Gultom and M. Silitonga, "Literatur review: kajian tanaman obat untuk mengatasi penyakit sistem saraf pusat di Indonesia [Literature review: study of medicinal plants to treat central nervous system diseases in Indonesia]," *Symbiotic: Journal of Biological Education and Science,* vol. 6, no. 1, p. 32–44, 2025, doi: 10.32939/symbiotic.v6i1.167.

[9] R. A. Azzahra, S. Sjaifuddin and L. Berlian, "Pengembangan media pembelajaran interaktif berbasis articulate storyline tema kelistrikan pada sistem saraf untuk menumbuhkan minat belajar siswa kelas ix [Development of interactive learning media based on articulate storyline on the theme of electricity in the nervous system to foster learning interest of 9th grade students]," *Jurnal Pendidikan MIPA,* vol. 13, no. 3, pp. 1-12, 2023. doi: 10.37630/jpm.v13i3.1135.

[10] S. Sarianti, M. F. Haruna and N. Nurlia, "Pengaruh penggunan model pembelajaran tipe two stay two stray (tsts) terhadap hasil belajar pada materi sistem saraf di SMA Negeri 2 Pulau Taliabu [The effect of using the two stay two stray (tsts) learning model on learning outcomes in nervous system material at SMA Negeri 2 Pulau Taliabu]," *Jurnal Biologi Babasal,* vol. 1, no. 2, p. 1–8, 2022, doi: 10.32529/jbb.v1i2.2070.

[11] S. D. Apriliyanti and N. Qomariyah, "Pengembangan media pembelajaran website "sarafku" pada submateri sistem saraf untuk melatih kemampuan literasi digital [Development of the learning media website 'my nerves' on the nervous system submaterial to train digital literacy skills]," *Berkala Ilmiah Pendidikan Biologi (BioEdu),* vol. 14, no. 2, pp. 530-540, 2025, doi: 10.26740/bioedu.v14n2.p530-540.

[12] A. Damayanti and U. N. A. D. Jayanti, "Development of biology smart card learning media based on character education in immune system material," *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan,* vol. 6, no. 2, pp. 179-190, 2024, doi: 10.20527/bino.v6i2.19155.

[13] F. Handayani and R. Rohani, "Development of katar-bio: smart card-based interactive media to improve of second-grade xi students' understanding and motivation in respiratory system topics," *Jurnal Pembelajaran Dan Biologi Nukleus,* vol. 11, no. 2, pp. 697 -718, 2025, doi: 10.36987/jpbn.v11i2.7598

[14] S. Solihin, A. S. N. Apriliani and A. N. N. Jannah, "ROCED: Robot card biology education as a media for biology learning," *JPBIO (Jurnal Pendidikan Biologi),* vol. 10, no. 1, pp. 35-49, 2025. doi: 10.31932/jpbio.v10i1.4227

[15] N. I. A. Syifa and N. B. Haka, "Developing islamic values-based biology smart cards for the eleventh-grade students of special school," *JPBIO (Jurnal Pendidikan Biologi),* vol. 6, no. 2, pp. 12-26, 2021, doi: 10.31932/jpbio.v6i2.1298

[16] S. Thiagarajan, D. S. Semmel and M. I. Semmel, *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook*, Bloomington: Indiana University, Center for Innovation in Teaching the Handicapped, 1974.

[17] Sugiyono, *Metode penelitian kuantitatif, kualitatif, dan R&D [Quantitative, qualitative, and R&D research methods]*, Bandung: Alfabeta, 2022.

[18] J. W. Creswell, *Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.)*, Thousand Oaks: Sage Publications, 2018.

[19] M. F. Imani and I. Nurmawati, "Development of interactive learning media using lectora inspire on nervous system topic for senior high school students," *Indonesian Journal of Mathematics and Natural Science Education,* vol. 3, no. 2, pp. 87–95, 2023, doi: 10.35719/mass.v3i2.77

[20] H. Tiana and R. Rohani, "Development of augmented reality (ar) learning media on digestive system materials in improving the understanding of concepts for students of class xi MAN 2 Langkat," *Sosioedukasi: Jurnal Ilmiah Ilmu Pendidikan Dan Sosial,* vol. 14, no. 2, pp. 1262–1275, 2025, doi: 10.36526/sosioedukasi.v14i3.6022.

[21] A. Ariyanto, W. H. Kristiyanto and R. A. Nugroho, "Effect of interactive media, make a match and lecture method on learning virus achievement," *Biosfer: Jurnal Pendidikan Biologi,* vol. 14, no. 1, pp. 36–53, 2021. doi: https://doi.org/10.21009/biosferjpb.17262

[22] P. Purwanti and A. W. Subiantiro, "Development of discovery-based nervourssy media on the topics of nervous system to improve digital literacy and critical thinking skills," *Jurnal Pendidikan MIPA (JPMIPA),* vol. 25, no. 2, pp. 620-636, 2024, doi: 10.23960/jpmipa/v25i2.pp620-636.

[23] A. M. Nurdin, A. Gofur, M. S. Sari and Munzil, "Technology-supported differentiated biology education: Trends, methods, content, and impacts," *EURASIA J Math Sci Tech Ed,* vol. 21, no. 3, pp. 2598, 2025, doi: 10.29333/ejmste/16044

[24] M. V. Zuhro, "A smartboard media in increasing science learning interest of students at santa ursula middle school, Jakarta," *International Conference on Education, Science, Technology and Health (ICONESTH),* vol. 10, no. 2, pp. 116–128, 2025, doi: 10.46244/iconesth.vi.349

[25] R. R. Jannah and G. M. C. Putra, "Feasibility of augmented reality integrated e-comics to improve learning outcomes," *Elementary School Forum (Mimbar Sekolah Dasar),* vol. 11, no. 3, pp. 557-571, 2024, doi: 10.53400/mimbar-sd.v11i3.75399.

[26] E. Choi, Y. Choi and N. Park, "Development of blockchain learning game-themed education program targeting elementary students based on ASSURE Model," *Sustainability,* vol. 14, no. 7, pp. 3771, 2022, doi: 10.3390/su14073771.

[27] E. N. Qorimah, S. Sutama and Y. M. Hidayati, "An augmented reality-based interactive learning application for teaching food chains in elementary schools," *Profesi Pendidikan Dasar,* vol. 11, no. 3, pp. 236–250, 2024, doi: 10.23917/ppd.v11i3.6145.

[28] E. Cahyaningsih, S. Shaleh and A. Fitriyanti, "Utilization of Computer-Based Testing Technology to Optimize Cognitive-Based Assessment Literacy in the Learning of Islamic Elementary School Students," *Journal of Integrated Elementary Education,* vol. 4, no. 2, p. 151–172, 2024. doi: https://doi.org/10.21580/jieed.v4i2.21943.

[29] F. Andini and S. Sapri, "Development of word board learning media to overcome reading difficulties of third grade elementary school students," *Al-Adzka: Jurnal Ilmiah Pendidikan Guru Madrasah Ibtidaiyah,* vol. 14, no. 2, p. 206–220, 2024, doi: 10.18592/aladzkapgmi.v14i2.14720.

[30] E. Heyd-Metzuyanim, A. J. Sharon and A. Baram-Tsabari, "Mathematical media literacy in the COVID-19 pandemic and its relation to school mathematics education," *Educational Studies in Mathematics,* vol. 108, no. 1, p. 201–225, 2021, doi: 10.1007/s10649-021-10075-8.
[31] R. Powell, J. Schultz, R. Harvey and A. Meaux, "Maximizing student outcomes in schools: data-driven individualized education program goals and objectives aligned to the standards," *Language, Speech, and Hearing Services in Schools,* vol. 55, no. 2, pp. 303-322, 2024, doi: 10.1044/2023LSHSS-23-00082
[32] N. Hasanah, E. Suhartini, T. Wahyuningsih, Y. Supriyatna, "Student and teacher responses to the use of media and teaching tools in the STEM boardgame," *Integrated Science Education Journal*, vol. 7, no. 3, pp. 547-59, 2026, doi: 10.37251/isej.v7i3.3314.
[33] R. J. M. Gotlieb and M. H. I. Yang, "Becoming literate: educational implications of coordinated neuropsychological development of reading and social-emotional functioning among diverse youth," *Literacy Research: Theory, Method, and Practice,* vol. 71, no. 1, pp. 23-45, 2022, doi: 10.1177/23813377221120107
[34] F. Rachmaningsih and T. Purnomo, "Validitas dan kefektifan video pembelajaran materi ekosistem menggunakan powtoon untuk meningkatkan hasil belajar siswa kelas x sma [The validity and effectiveness of learning videos on ecosystem material using powtoon to improve learning outcomes for 10th grade high school students]," *Berkala Ilmiah Pendidikan Biologi (BioEdu),* vol. 13, no. 2, pp. 392-404, 2024, doi: 10.26740/bioedu.v13n2.p392-404.
[35] A. Almardiyah, E. Khalid, B. R. Fajri and Q. Akyuni, "Sustainable development: implementation and impact of augmented reality in islamic history learning," *Khalifa: Journal of Islamic Education,* vol. 9, no. 1, pp. 52–66, 2025, doi: 10.24036/kjie.v9i1.189
[36] L. Vaquero, K. Groves, E. L. M. Vidal, K. James, J. L. Marlor, C. McIntyre, L. Ostia, S. Sirota, L. Shields, F. Degé, E. García-Mingo and P. Ripollés, "Studying the effects of digital arts-based interventions on teenagers' social media usage, brain connectivity, and mental health: study protocol of the SMART project," *European Journal of Psychotraumatology,* vol. 16, no. 1, pp. 2550079, 2025, doi: 10.1080/20008066.2025.2550079.
[37] F. Amalia, and K. Manalu, "Development of socio-scientific issues based reproduction e-module to enhance critical thinking skills," *Jurnal Mangifera Edu*, vol. 10, no. 1, pp. 95-113, 2025, doi: 10.31943/mangiferaedu.v10i1.243.
[38] K. A. Maharani, S. S. A. Q. Barid, S. R. D. Astuti, and S. Wahyuni, "Integration of digital media in the discovery learning model to enhance junior high school students conceptual understanding in science: a review," *Jurnal Pijar Mipa*, vol. 21, no.1, pp. 74-85, 2026, doi: 10.29303/jpm.v21i1.10924.
[39] K. T. Nigussie, B. K. Semahagn, B. S. Mersha, and A. B. Tamiru, "Effects of paper-based problem scenarios on high school biological problem-solving skills and academic achievement," *Disciplinary and Interdisciplinary Science Education Research*, vol. 7, no. 1, pp. 21, 2025, doi: 10.1186/s43031-025-00138-8.
[40] J. R. Honra, "Enhancing high school biology education students' transdisciplinary thinking through design thinking," *The Journal of Experimental Education*, pp. 1-17, 2025, doi: 10.1080/00220973.2025.2606241.
[41] M. A. A. M. Hamizi, and N. A. M. Mokmin, "Enhancing secondary biology learning through guided and problem-based virtual reality: effects on interest, concentration, and performance," *Education and Information Technologies*, vol. 31, no. 3, pp. 755-785, 2026, doi: 10.1007/s10639-025-13840-x.
[42] J. Wibowo, A. F. Hindriana, and Z. Abidin, "Metaphor-Based visual media for cell biology instruction: effects on students' science literacy and metacognitive skills," *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, vol. 11, no. 1, pp. 146-158, 2026, doi: 10.24042/tadris.v11i1.28912.
[43] A. S. Evmenova, K. Regan, R. Mergen and R. Hrisseh, "Educational games and the potential of ai to transform writing across the curriculum," *Education Sciences,* vol. 15, no. 5, pp. 567, 2025, doi: 10.3390/educsci15050567
[44] M. A. N. Elmaadaway, M. E. El-Naggar and M. R. I. Abouhashesh, "Improving primary school students' oral reading fluency through voice chatbot-based AI,"*Journal of Computer Assisted Learning,* vol. 41, no. 2, pp. 70019, 2025. doi: 10.1111/jcal.70019.
[45] C. Zhao and J. Yu, "Relationship between teacher's ability model and students' behavior based on emotion-behavior relevance theory and artificial intelligence technology under the background of curriculum ideological and political education," *Learning and Motivation,* vol. 88, no. 1, pp. 102040, 2024. doi: 10.1016/j.lmot.2024.102040.
[46] T. Tanti, W. Utami, D. Deliza, and M. Jahanifar, "Investigation in vocation high school for attitude and motivation students in learning physics subject", *Journal Evaluation in Education (JEE)*, vol. 6, no. 2, pp. 479-490, 2025, doi: 10.37251/jee.v6i2.1452.
[47] N. Pancawati, M. Widayati and N. Nurnaningsih, "Aktualisasi game edukatif digital pada perkembangan kemampuan literasi baca tulis anak usia dini [The actualization of digital educational games in the development of early childhood reading and writing literacy skills]," *Journal of Education Action Research,* vol. 8, no. 4, pp. 624–635, 2024, doi: 10.23887/jear.v8i4.86023.
[48] B. E. Tijani, and A. M. Adeduyigbe, "Transforming science education: A systematic review of evidence-based strategies for cultivating 21st-century skills in STEM education," *Journal of Research in Environmental and Science Education*, vol. 3, no. 1, pp. 8-23, 2026, doi: 10.70232/jrese.v3i1.37.
[49] T. Oktasari, S. M. Siahaan, and L. Marlina, "The role of STEM-based learning media in improving students' science literacy: A systematic review," *Jurnal Inovasi Teknologi Pendidikan*, vol. 12, no. 4, pp. 419-432, 2025, doi: 10.21831/jitp.v12i4.85336.
[50] Y. Xie, and A. Yusuf, "Advancing scientific literacy: A systematic review of trends, pedagogies and challenges in the 21st century," *Review of Education*, vol. 14, no. 1, pp. 70140, 2026, doi: 10.1002/rev3.70140.
[51] I. Sari, R. J. P. Akhmadi, S. D. Puspitasari, S. J. J. Kausar, and S. Ananda, "Enhancing contextual scientific literacy through the integration of STEM in biology education in the society 5.0 era: A literature review," *Journal of Biology Creative Education*, *2*(2), 88-96, 2025, doi: 10.20527/bioco.v2i2.16330.