International Journal of Learning, Teaching and Educational Research
Vol. 24, No. 2, pp. 543-559, February 2025
https://doi.org/10.26803/ijlter.24.2.27
Received Dec 25, 2024; Revised Feb 11, 2025; Accepted Feb 22, 2025

AI-Driven Sociocultural Interactive Digital Module for Papua: Advancing Educational Technology to Sustainable Development Goals

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Abstract. This study presented the development and evaluation of an artificial intelligence driven interactive digital module designed for middle-school science education in Papua and integrating sociocultural content with topics aligned to PISA 2025. The module aimed to enhance educational outcomes while supporting the Sustainable Development Goals. A mixed-methods approach was used, combining qualitative ethnographic research to embed relevant cultural elements with quantitative assessments of the module's impact on science literacy. The study involved 200 middle school students and 40 science teachers, who were divided into two groups: an experimental group using the artificial intelligence based module and a control group following the standard curriculum. Data analysis was conducted using a paired-sample t-test to determine the statistical significance of learning improvements. Instruments included pre- and post-tests, surveys, and focus group discussions with students and teachers. The data analysis showed a 49.19% improvement in understanding complex scientific concepts. This improvement was observed particularly in the structure and properties of matter, earth and space systems, global-warming climate change, chemical changes of matter, energy, motion and forces, light waves, radio, sound, seismic activity, and absorption of radiation by CO_2. The findings highlighted the effectiveness of culturally responsive digital education tools in improving science literacy in underrepresented regions. Recommendations included expanding the module's use to other regions with similar educational challenges and developing AI features to enhance personalized learning experiences in science education.

Keywords: artificial intelligence; sociocultural; Interactive Digital Module; educational technology

1. Introduction

Papua, a region of Indonesia characterized by significant cultural diversity and geographical remoteness, encounters distinct problems in providing quality education to its inhabitants (Fiharsono et al., 2024). The extensive and diverse terrain together with inadequate infrastructure and resources hinders pupils in rural areas from accessing educational opportunities that are equivalent to their urban counterparts (Nerenberg, 2019). This discrepancy is particularly pronounced in science education, as students frequently struggle with literacy in essential scientific topics. Language difficulties, particularly relating to the fact that Indonesian is not the native language for many children, exacerbate their capacity to comprehend classes aligned with the national curriculum. The disparity between the national scientific curriculum and the local reality of Papuan pupils fosters a context in which the subject appears irrelevant to their everyday lives (Griethuijsen et al., 2015). Integrating sociocultural content into the science curriculum can be achieved by embedding local knowledge and traditions into learning materials while maintaining national uniformity through a modular approach that supplements rather than replaces standardized content, ensuring both cultural relevance for rural students and alignment with national educational objectives. Studies indicate that pupils are more inclined to interact with and comprehend content that is pertinent to their lives and cultural contexts (Carlsen & Bruggemann, 2022; Radcliffe et al., 2016).

In Papua, traditional ecological knowledge and cultural practices concerning the environment and land management are profoundly embedded in the community. Educators can facilitate the connection between abstract scientific concepts and students' real experiences by integrating these aspects into science classes. Biodiversity, conservation, and principles of climate change can be associated with local behaviors, including sustainable land use and traditional fishing techniques. This method enhances engagement and offers students a more profound comprehension of the application of science in their surroundings (Carlsen & Bruggemann, 2022). The sociocultural context of education plays a crucial role in shaping learning experiences and outcomes. This context encompasses cultural norms, social interactions, and institutional practices, all of which influence how knowledge is constructed and disseminated within educational settings. Grounded in Vygotsky's sociocultural theory, learning is viewed as an inherently social process that occurs within specific cultural contexts (Bitskinashvili, 2018; Zhou, 2024). Social interactions and cultural tools are pivotal in cognitive development, emphasizing that education must be aligned with the sociocultural realities of the learners.

This study corresponds with the United Nations Sustainable Development Goal (SDG) 4, which underscores the provision of inclusive and equitable quality education for all individuals (Whittingham et al., 2023). Notably, the fourth Sustainable Development Goal (SDG 4) aims to address marginalized and underserved communities, such as those in Papua, and to guarantee equitable access to quality education that is comparable to that of their counterparts in more developed areas (Della Santa Navarrete et al., 2020; Tsalis et al., 2020). This study aimed to enhance educational equity by examining the nexus of cultural relevance and academic success. Creating an AI-driven Interactive Digital Module (IDM) was essential for accomplishing this objective. Integrating local cultural components into the module enhances the educational experience for Papuan students, enabling them to connect the scientific principles they are studying to their everyday life (Henukh et al., 2021, 2023; Setiawan et al., 2017).

This study also targets the objectives of PISA 2025, which aims to enhance students' capacity to apply scientific knowledge to practical issues (Henukh et al., 2021; Teig et al., 2022). A primary criticism of conventional science education is its focus on rote memorization instead of fostering critical thinking and practical application (Bailey et al., 2023). By contrast, PISA tests assess students on their capacity to employ scientific reasoning in addressing practical, real-world problems. In areas such as Papua where environmental alterations such as deforestation, biodiversity depletion, and climate change effects are readily apparent, students must comprehend how science may be employed to tackle these urgent challenges (Broderick, 2023). Creating a curriculum that instructs students on scientific principles and relates them to local environmental issues enables the students to engage actively in discussions around sustainability and conservation.

This research investigated the challenges faced by students in Papua, Indonesia, in accessing quality science education due to geographical isolation, cultural differences, and language barriers. These issues hinder their ability to grasp essential scientific concepts and engage with the curriculum effectively. The study explored how integrating sociocultural content into the science curriculum through an AI-driven interactive digital module (IDM) can bridge this gap. By embedding local knowledge and aligning it with national science standards, the research aims to enhance science literacy and student engagement. This approach not only addresses educational inequities but also supports the SDGs, particularly in providing equitable education for marginalized communities.

The research questions that were the focus of this study are as follows:
1. How to develop an AI-based interactive module that integrates sociocultural content with science topics relevant to PISA 2025?
2. How does the module influence the science literacy of secondary school students?
3. How can the integration of sociocultural content in digital learning tools improve student engagement and understanding?

This research aimed to develop and evaluate an AI-based IDM designed for science education in Papua. This module not only contains scientific content relevant to PISA context but also integrates sociocultural elements that are important to the Papuan community.

2. Literature Review

Artificial Intelligence (AI) in education offers a distinctive opportunity to meet the varied learning requirements of Papuan students (Kuleto et al., 2021). Moreover, artificial intelligence driven solutions can customize the educational experience by modifying content according to individual advancement and understanding (Ouyang & Jiao, 2021). For instance, if a student encounters difficulties comprehending the notion of energy transfer, the AI system can offer further resources, elucidations, and exercises customized to their particular need. This degree of customization ensures that students continue to make progress, regardless of their varying rates of advancement, while adhering to the curriculum (Jafari & Keykha, 2024). In an area where educators may occasionally lack the time or resources to offer personalized attention to each student, AI can bridge this gap and facilitate a more equitable educational experience.

One of AI's most significant contributions to education is its potential to personalize learning experiences. Adaptive systems adjust to each learner's needs, allowing students to progress at their own pace. This includes AI-driven assessments that optimize learning by adjusting question difficulty based on previous responses (de Oliveira Silva & dos Santos Janes, 2020). Furthermore, artificial intelligence enhances the assessment process by providing real-time feedback, enabling educators to offer timely, personalized insights to students, particularly in larger classrooms where individual attention is often limited (Henukh, 2021; Tubino & Adachi, 2022). These advancements improve not only student outcomes but also the efficiency of educational practices.

The IDM augments student engagement by integrating multimedia components, including animations, interactive simulations, and practical problem-solving activities. These attributes render learning more dynamic and interesting, especially for students who have difficulties with conventional textbook-based training (Wu, 2024). Interactive simulations enable students to comprehend intricate scientific processes such as the greenhouse effect or the water cycle in a more intuitive and accessible manner (Almusaed et al., 2023). Linking these simulations to local environmental challenges, such as the impact of climate change on Papuan ecosystems, allows students to observe the significance of their studies directly. Moreover, the IDM not only improves student engagement but also offers real-time feedback on student progress, enabling teachers to assess students' comprehension of the topic. This input is essential for pinpointing areas where students may want more assistance, especially in traditionally difficult disciplines such as physics or chemistry (Astra, Aminudin et al., 2021; Astra, Henukh et al., 2023; Lazou & Tsinakos, 2023).

The integration of digital interactive modules in science learning has gained significant attention due to the modules' potential to enhance student engagement, motivation, and learning outcomes. These interactive multimedia tools create dynamic and flexible learning environments, allowing students to explore content in ways that traditional methods may not support. For instance, Budiarto and Jazuli (2021) argue that interactive learning multimedia can simplify the delivery of complex scientific concepts, thus improving students' understanding and overall performance (Budiarto & Jazuli, 2021; Henukh et al., 2019, 2022).

Educators can utilize this data to modify lessons and deliver targeted interventions for underperforming pupils. The AI technology of the module provides students with instantaneous feedback on their work, facilitating the correction of errors and enhancing their learning prior to advancing to more intricate subjects (Astra, Aminudin et al., 2021; Lee et al., 2021). This cyclical learning method cultivates confidence and promotes a growth mentality, motivating pupils to persevere despite challenging subjects. Ultimately, incorporating sociocultural content into the curriculum improves learning results and fosters a sense of cultural pride and identity among students (Wiggan & Watson, 2016).

In numerous indigenous cultures, formal education, especially in the sciences, may often appear disassociated from the cultural traditions and values of the society. Artificial intelligence driven IDM integrates indigenous knowledge and practices into the curriculum, thereby validating the significance of the cultural legacy of Papuan students while equipping them for contemporary difficulties (Zidny et al., 2020). The simultaneous emphasis on academic excellence and cultural significance is essential for cultivating a generation of students who possess scientific literacy and a strong sense of cultural identity. The creation of the AI-driven IDM signifies a substantial advancement in tackling the educational obstacles encountered by pupils in Papua.

This study sought to enhance science literacy, student engagement, and overall educational outcomes in the region by encompassing local sociocultural content. Examples include traditional Papuan ecological knowledge in sustainable fishing and land use practices. Indigenous methods of food preparation, such as stone-burning cooking techniques, are used to explain heat transfer and energy conservation. Cultural storytelling traditions convey environmental stewardship and illustrate biodiversity and sustainability concepts that align with SDG 4 and PISA 2025 objectives. Additionally, AI technologies are used to provide tailored learning experiences. The science subject provides students with essential knowledge for academic success and enables them to apply this knowledge to the distinct difficulties within their communities (Kahu & Nelson, 2018).

3. Methodology

In this study, a mixed-methods approach was used that combined qualitative and quantitative data to assess the effectiveness of the AI-based interactive module (Strijker et al., 2020). The research was conducted in two stages. The first stage was a qualitative ethnographic study that aimed to embed local sociocultural elements into the science curriculum such as Papuan traditional ecological knowledge in sustainable fishing and land management, indigenous food preparation techniques such as stone-burning to explain heat transfer and energy conservation, local myths and folklore to contextualize environmental concepts, traditional navigation and astronomy to introduce space science, and rituals related to natural phenomena to explain scientific processes such as weather patterns and climate change. The second stage involved a quantitative assessment to measure the impact of the module on students' science literacy. The study involved 200 secondary school students from several schools in Papua and 40 science teachers who participated in focus group discussions (FGDs), all selected using purposive sampling. The students were divided into two groups: an experimental group that used the AI-based module and a control group that followed the standard curriculum. The group assignment was based on ensuring that both groups had comparable demographic characteristics, prior science literacy levels, and access to learning resources. This approach allowed for a fair evaluation of the module's effectiveness.

The data analysis was conducted using a paired-sample t-test to determine the statistical significance of learning improvements. The instruments used to collect the data included pre- and post-tests. The study used pre-tests, post-tests, surveys, and FGDs to evaluate the effectiveness of the AI-driven IDM in enhancing science literacy. The pre-test and post-test assessments were based on the PISA 2025 science framework and covered key scientific concepts such as matter, energy, climate change, and biodiversity. These tests included multiple-choice tests to measure science literacy and problem-solving skills. The pre-test established students' baseline knowledge, while the post-test measured learning gains after using the module. Surveys and focus group discussions (FGDs) provided additional insights into user experiences. Surveys, using Likert-scale and open-ended questions, assessed usability, engagement, and cultural relevance. The FGDs were conducted separately with students and teachers, exploring student learning experiences and teacher perspectives on classroom implementation. Data from these discussions were thematically analyzed to understand the module's impact on science literacy and engagement, ensuring a comprehensive evaluation of its effectiveness in integrating sociocultural elements into science education.

4. Results and Discussion

The main objectives of this study were to develop an AI-based interactive module that integrated sociocultural content with science topics relevant to PISA 2025, to evaluate its impact on science literacy among secondary school students, and to explore how sociocultural integration into digital tools can improve student engagement and understanding. The results of this study are presented in accordance with these objectives.

4.1 Improvement in Science Literacy

The module was successfully developed by integrating local cultural narratives, environmental challenges, and Papuan traditional knowledge. These are linked to the science topics covered in PISA 2025 such as the structure and properties of matter, earth and space systems, and energy. The AI component personalizes the learning path for students, tailoring the content to their performance and understanding. The results of the cultural integration into the IDM using AI can be seen in Figure 1.

Sosiokultural Papua

Upacara adat bakar batu

Gambar 3.22. Upacara adat bakar batu, papua
Sumber : indonesia.tourism.com

Upacara adat Bakar Batu adalah salah satu ritual penting dalam budaya Papua, terutama di kalangan masyarakat di wilayah pegunungan Papua, seperti suku Dani, Lani, dan Yali. Upacara ini memiliki filosofi dan makna yang mendalam, serta berperan penting dalam kehidupan sosial dan spiritual masyarakat Papua. Upacara adat Bakar Batu di Papua bukan hanya sekadar ritual memasak makanan, tetapi juga merupakan simbol penting dari persatuan, hubungan spiritual dengan alam, transformasi sosial, dan kesejahteraan komunitas. Ritual ini menggambarkan kedalaman filosofi budaya Papua yang menghargai harmonisasi dengan lingkungan, penghormatan terhadap roh leluhur, dan kekuatan tradisi dalam kehidupan sehari-hari. Dalam upacara Bakar Batu, batu panas digunakan untuk memasak makanan dalam lubang tanah. Teknik ini menunjukkan pemanfaatan sumber daya alam dengan cara yang minim dampaknya terhadap lingkungan. Batu-batu tersebut, setelah digunakan, dibiarkan kembali ke alam tanpa merusak ekosistem. Hal ini mencerminkan prinsip pemanfaatan sumber daya yang berkelanjutan dan minim dampak lingkungan.

Figure 1: Papua's stone-burning culture

The practice of burning stones in Papua is associated with the scientific literacy highlighted in PISA 2025, particularly regarding the application of science in daily life. The practice of heating stones for culinary purposes exemplifies the application of scientific principles such as heat conduction and chemical transformations in food. These principles are pertinent to students' comprehension of real-world scientific phenomena, as well as the mathematics and reading skills evaluated in PISA 2025. Students can comprehend the transfer of thermal energy and how traditional cooking methods demonstrate an awareness of ecosystems and sustainability (Mälkki & Alanne, 2017). Furthermore, PISA 2025 evaluates the problem-solving and critical thinking skills of students, and these may be associated with the investigation of stone-grilling methods. Students may be motivated to analyze the functionality of these methods critically and to determine how scientific principles such as energy transfer and resource efficiency can be used to enhance cooking efficiency. Together with the emphasis of PISA 2025 on cultivating scientific reasoning and problem-solving abilities in practical contexts, this tradition promotes scientific inquiry and innovation.

Below is an example of conduction in which heat energy is transferred from hotter molecules (fire) to cooler molecules (rock). The formula that describes conduction heat transfer is as follows:

$$Q = k.A.\frac{\Delta T}{d} \quad (1)$$

where the heat transfer rate (J/s or Watt) is Q, thermal conductivity of the stone is k, contact surface area between the stone and the fire is A, temperature difference between the fire and the stone is ΔT, and thickness of the stone receiving heat is d.

Fire also emits energy in the form of electromagnetic radiation. The heat of the fire radiates to the stone and the surrounding air. The formula that describes heat radiation is based on the Stefan-Boltzmann Law:

$$P = \sigma . A . (T^4 - T_{ambient}{}^4) \quad (2)$$

where radiation power (W) is P, Stefan-Boltzmann constant (5.67×10-8W/m^2K^4) is σ, surface area of the radiating object is A, rock surface temperature (K) is T, and ambient temperature (K) is $T_{ambient}$.

Below is an example of convection: When hot stones are placed on or in the ground, the hot air surrounding the stones begins to rise, and cooler air moves in to replace it. This is heat transfer through natural convection. The formula for convection heat transfer is as follows:

$$Q = h . A . (T_{stone} - T_{air}) \quad (3)$$

where the heat convection coefficient is h, surface area of the stone is A, temperature of the stone is T_{stone}, and temperature of the ambient air is T_{air}.

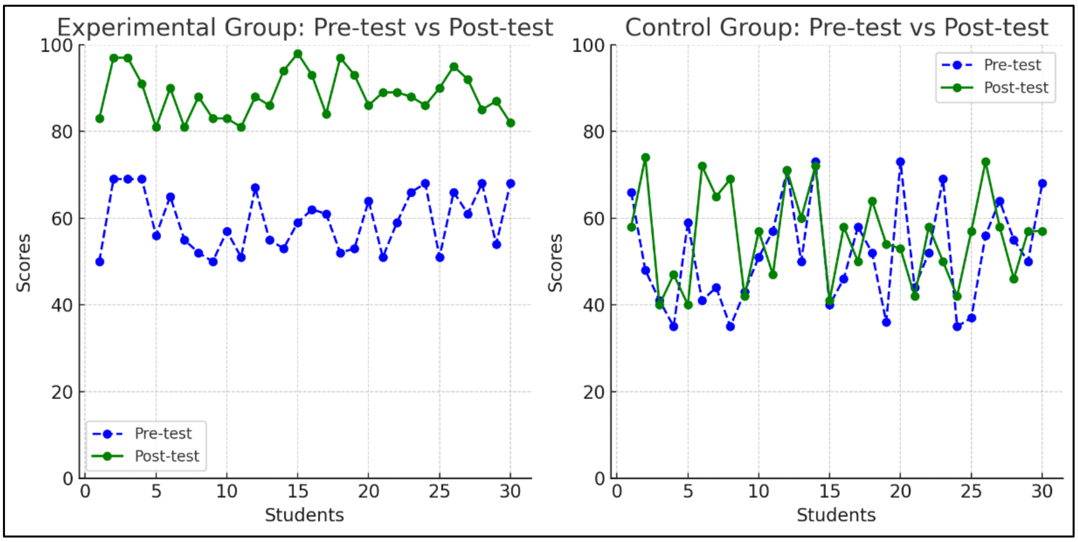
Moreover, this can assist students in comprehending the significance of environmental sustainability and the effects of human actions on local ecosystems. Through assessment of the use of sustainable natural resources in traditional practices, students are prompted to cultivate both global and local understanding of sustainability challenges together with the significance of environmental sustainability (Shrivastava et al., 2020).

The Stone Burning Ceremony encompasses the transport of heat via three primary mechanisms: conduction, radiation, and convection. When the stones are in direct contact with the fire, heat is transferred via conduction, elevating the stones to a temperature that is adequate for cooking food. Furthermore, radiation from the fire contributes to the heating of the stones without direct contact, while convection facilitates the uniform distribution of heat around the stones for optimal cooking. This ceremony also generates greenhouse gasses notably CO_2 (Aminbeidokhti et al., 2016). The CO_2 that is emitted from wood combustion exacerbates global warming via the greenhouse effect, which elevates global temperatures by sequestering infrared radiation in the atmosphere. Despite the ritual's limited scope, the aggregate consequences of such combustion substantially influence climate change.

Nonetheless, the Stone Burning event exemplifies traditional energy efficiency. The heated stones that are employed may retain and gradually emit heat for cooking, eliminating the necessity for ongoing supplementary fuel. This method embodies the use of sustainable and minimalist energy, employing natural resources judiciously and without waste. This ceremony is pertinent to SDG 4, which emphasizes quality education (Shrivastava et al., 2020). The youth of Papua acquire knowledge regarding sustainability and coexistence with nature through this ritual. This conventional practice imparts the judicious use of resources and awareness of environmental concerns, fostering ecological accountability and a comprehensive understanding of the difficulties posed by climate change.

4.2 Impact on Science Literacy

Quantitative data from the initial and concluding assessments indicated a substantial enhancement in the science literacy of students using the AI-based curriculum. The examination scores of the experimental group improved by 49.19%, particularly regarding matter, earth and space systems, climate change, chemical changes, energy, motion, waves, sound, radiation absorption, and biodiversity. Conversely, the control group, which adhered to the traditional curriculum devoid of the modules, only indicated a small improvement. The results can be seen in the Figure 2.



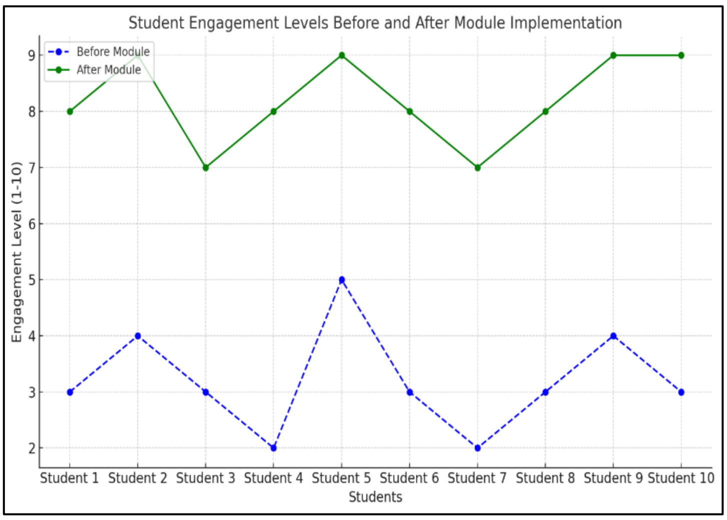
The graph above illustrates a comparison between the pre-test and post-test outcomes for the experimental and control groups, with a maximum score of 100. In the experimental group comprising students who had engaged with the AI-driven IDM over six weeks, the majority of the pre-test scores ranged from 50 to 70. Following the intervention, which incorporated interactive lessons, AI-adaptive exercises, and real-time feedback facilitated by trained science teachers, students' post-test scores markedly improved, reaching a range of 80 to 100. This significant increase indicates that the intervention effectively enhanced students' overall performance, with most students demonstrating consistent and incremental improvement.

In contrast, the control group, which followed the standard curriculum without the intervention, exhibited more variable pre-test scores between 35 and 75. After the post-test, only a marginal improvement was observed, with most students maintaining scores similar to their pre-test results or showing only modest increases. The absence of a structured intervention in this group suggested that traditional instructional methods alone had a limited impact on enhancing student learning outcomes. Although there was some improvement after the post-test, in general, the change in students' scores was not substantial. Most students remained within the same score range or only experienced a very small improvement. This indicated that the learning method applied to the control group was less effective in improving students' learning performance. Therefore, it can be concluded that the different learning approaches between the two groups produced different impacts on student learning outcomes (Aminbeidokhti et al., 2016; Pires et al., 2024).

The 49.19% increase in average score in the experimental group compared to the slight 8.07% increase in the control group indicated that the special treatment in the form of learning methods or interventions in the experimental group played an important role in promoting better understanding. This provides empirical evidence that innovation in learning methods can have a significant impact in improving the quality of student learning (Lin et al., 2016). In contrast, the lack of effective intervention in the control group suggests that conventional learning methods may not be sufficient to improve comprehension substantially.

The t-test results showed a t-statistic value of *8.40* with a p-value of $1.31e^{-11}$ (very small—far below 0.05). This indicated that the difference between the experimental and control groups was highly statistically significant. Therefore, it can be concluded that the intervention conducted on the experimental group had a significant impact and did not happen by chance. The intervention was effective in improving students' learning outcomes (Colucci-Gray et al., 2013; Harackiewicz & Priniski, 2018).

4.3 Enhancement of Student Engagement and Understanding
Feedback from students and teachers indicated that the integration of sociocultural content into the module significantly improved engagement. Students reported that linking scientific concepts to environmental issues and local cultural practices helped them to understand the material better (Colucci-Gray et al., 2013). The results of the analysis on the enhancement of student engagement and understanding can be seen in Figure 3.



The graph comparing students' involvement levels before and after the implementation of the module indicated a substantial improvement in learning engagement. Prior to the implementation of the module, student engagement levels were inconsistent and generally low, with scores fluctuating between 2 and 5. This suggested that before the intervention, the majority of students exhibited minimal engagement with the learning material or process. Subsequent to the implementation of the module, substantial changes transpired. All students demonstrated heightened involvement, with engagement levels ranging from 7 to 9. This rise indicated that the module effectively enhanced students' interest and engagement in learning (Lin et al., 2018). Engagement, which was formerly poor, has now become more consistent, with each student demonstrating significantly more involvement than prior to the module's deployment. This figure demonstrates that the implementation of the module significantly enhances students' learning engagement. This figure demonstrates that implementation of the module significantly enhances students' learning engagement. Student involvement, originally subpar, significantly improved following the intervention, demonstrating that the module positively influenced student motivation and participation in the learning process.

4.4 Teacher and Student Feedback on the AI-Driven Module

Teacher feedback emphasized the effectiveness of the module in meeting students' diverse learning needs, especially through AI-driven personalized learning pathways. Teachers observed that students who had difficulty with certain topics received additional resources and assignments, which helped to improve their understanding.

Table 1: Teacher and student feedback on AI-driven personalized learning with teacher comments and student quotations

Feedback Aspect	Teachers' Perspective	Students' Perspective	Teacher Comments	Student Quotes
Tailored Learning Paths	The AI system provided customized exercises and explanations, reducing the need for constant one-on-one support. Teachers could focus more on the class as a whole.	Students appreciated that the module adapted to their individual learning pace, allowing them to spend more time on challenging topics without feeling left behind.	"The personalized paths meant I could focus on more complex issues with students who needed it, while others progressed on their own."	"I liked that I could take my time with things I didn't understand, and I didn't feel rushed."
Instant Feedback and Continuous Improvement	Teachers valued the module's immediate feedback, which helped students learn independently and reduced	Students found the instant feedback helpful in correcting mistakes quickly, and this allowed for faster learning and boosted their confidence.	"The immediate feedback helped students correct their own mistakes, and I could see	"When I got something wrong, I could try again right away, so I learned faster."

Feedback Aspect	Teachers' Perspective	Students' Perspective	Teacher Comments	Student Quotes
	repetitive questions in class.		their confidence growing lesson by lesson."	
Customized Challenges for Advanced Learners	The AI provided advanced tasks for high achievers, keeping them engaged while allowing teachers to focus on students who needed more help.	Advanced students appreciated being able to move beyond the regular curriculum, tackling more formal tasks that kept them engaged and challenged.	"It was great to see students who were usually ahead being challenged without me having to prepare separate lessons just for them."	"I liked that when I finished early, I got harder problems. It kept me interested."
Reduced Stress and Increased Confidence	Teachers observed that because of the personalized learning paths, students who typically struggled under pressure became more relaxed and confident.	Students felt more in control of their learning, which reduced their anxiety. The ability to retry tasks without judgment helped to build their confidence and make learning enjoyable.	"My quieter students came out of their shells; they weren't afraid to make mistakes anymore because they knew they could try again."	"I didn't feel scared of getting it wrong because I could try as many times as I needed to. It made me feel more confident."

Table 1 compares teacher and student feedback on AI-driven personalized learning modules, emphasizing different aspects of its implementation and efficacy. From the educators' standpoint, AI was crucial in personalizing the learning trajectories for students through the provision of tailored activities, thus enabling teachers to minimize the time allocated to repetitive work and to concentrate more on collective education (Bayly-Castaneda et al., 2024). Educators recognized the significance of immediate feedback in fostering ongoing enhancement and accelerated learning. Students perceived the AI-adapted learning paths as advantageous, enabling them to regulate their learning rate without experiencing undue pressure. This adaptable strategy enhanced students' confidence and motivated them to concentrate on problematic regions. Table 1 reveals that advanced students thrived on tailored assignments that maintained their engagement and enabled them to address more intricate content beyond the standard curriculum. Educators acknowledged the significance of advanced activities to sustain the engagement of high-achieving students while directing their support toward those requiring further assistance (Barber & Torney-Purta, 2008).

Both groups concurred that the module's immediate feedback mechanism was essential in assisting students to rectify their errors in real time, thereby promoting a more proactive and assured learning experience. Students valued the opportunity to rectify their errors promptly, which improved their comprehension and diminished the probability of recurring mistakes. Both teachers and students identified reduced stress and heightened confidence as key results. Students reported an increased sense of autonomy in their learning, resulting in less anxiety and more enjoyment of the educational experience. The conducive environment created by the AI system, as reported by educators, enabled traditionally struggling learners to experience increased comfort and confidence in their capabilities. This assurance was further strengthened by the capacity to obtain prompt feedback, allowing the students to assume responsibility for their education and to capitalize on their achievements (James et al., 2022; Simbolon et al., 2025; Trombly, 2020).

5. Conclusion

In conclusion, the AI-driven IDM developed in this study successfully enhanced science literacy among middle school students in Papua by integrating relevant sociocultural content with AI-driven learning tools. This approach highlights the potential of digital education tools in supporting the SDGs, particularly in improving access to quality education for underrepresented regions. Expanding the use of such tools to areas facing similar educational challenges could help to bridge the global education gap by providing more inclusive and culturally responsive learning experiences.

Despite the promising results, certain limitations must be acknowledged. Since the study was conducted specifically in Papua, its findings may not be fully generalizable to other regions without modifications. Additionally, the reliance on digital tools necessitates stable technological access, which may not always be available in underdeveloped areas. Although the module was designed to function in low-connectivity environments, further research is needed to optimize its effectiveness in areas with minimal or no internet access. Future studies should explore the integration of advanced AI features such as real-time data analytics to enhance personalized learning and track student progress, ultimately informing instructional strategies and policy decisions for broader educational impact.

6. Acknowledgments

We would like to express our sincere gratitude to DRPM Kemendikburistek for their financial support through the grant 062/E5/PG.02.00.PL/2024 dated 11 June 2024, which made this study possible.

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