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Development of the SINGA E-Module Integrating Ethno-STEM, Gamification, and Deep Learning Principles for Elementary Science Learning

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ABSTRACT

The low level of scientific literacy among elementary school students and the limited use of contextual and interactive digital teaching materials remain challenges in science learning. This study aimed to develop the SINGA E-Module, which integrates the Ethno-STEM approach, gamification, and deep learning principles as digital teaching material for science learning in elementary schools, and to determine its validity and practicality. This study employed a Research and Development (R&D) method using the 4D model, limited to the develop stage. The development stages included define, design, and develop, encompassing expert validation and practicality testing. The validation process involved three validators, consisting of a subject matter expert, a media expert, and a cultural expert, while the practicality test involved five teachers and fifteen fifth-grade elementary school students. Data were collected using validation sheets and practicality questionnaires and were analyzed descriptively using quantitative percentage analysis. The results showed that the SINGA E-Module was categorized as very valid based on the evaluations of the subject matter expert (89.57%), media expert (93.00%), and cultural expert (94.00%). In addition, the practicality test results indicated that the SINGA E-Module was categorized as very practical based on teachers' evaluations, with an average percentage of 90.40%, and students' evaluations, with an average percentage of 90.20%. Therefore, the SINGA E-Module is feasible for use as a digital teaching material to support more contextual and student-centered science learning in elementary schools.

Keywords: SINGA E-Module, Ethno-STEM, gamification, deep learning, elementary school

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INTRODUCTION

The advancement of science, technology, and digital transformation has reshaped the competencies required in the 21st century (Chen et al., 2023; Kain et al., 2024). Education is no longer solely oriented toward the acquisition of knowledge but is also directed at developing critical thinking, problem-solving, creativity, collaboration, and scientific literacy as essential competencies for addressing global challenges (Alamsyah et al., 2023; Chand, 2026; Anggriani & Atmojo, 2022). In the context of elementary education, science learning plays a vital role in enabling students to understand natural phenomena scientifically, make evidence-based decisions, and relate scientific concepts to everyday life (Anggriani & Alpusari, 2024; Atmojo et al., 2025). Therefore, science learning should be designed to be contextual, active, and meaningful in order to establish a strong foundation of scientific literacy from an early age.

However, findings from various international assessments indicate that the scientific literacy of Indonesian students remains at a low level. The results of the Programme for International Student Assessment (PISA) show that most students continue to experience difficulties in explaining scientific phenomena, evaluating evidence, and applying scientific concepts to solve contextual problems (OECD, 2023). This condition is closely associated with instructional practices that are still predominantly characterized by one-way knowledge transmission, resulting in students becoming passive recipients of information. Consequently, the learning process provides limited opportunities for students to engage in inquiry, think critically, or relate scientific concepts to real-life experiences in their surrounding environment (Atmojo et al., 2025).

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One approach that has been widely recommended to address these challenges is STEM (Science, Technology, Engineering, and Mathematics) based learning (Akif et al., 2025; Archer et al., 2025; Han & Guo, 2025). Numerous studies have demonstrated that the STEM approach can enhance critical thinking, creativity, problem-solving skills, and scientific literacy through interdisciplinary learning that is oriented toward solving authentic problems (Atmojo et al., 2024; Li et al., 2019; Papadakis et al., 2021; Wang et al., 2022). Nevertheless, the implementation of STEM in elementary schools continues to face several challenges, one of which is the suboptimal integration of scientific concepts with socio-cultural contexts that are closely related to students' daily lives. In fact, learning that incorporates local culture has been shown to enhance the meaningfulness of learning while strengthening students' cultural identity (Mahrinasari et al., 2024; Noviana et al., 2023; Sakti et al., 2024).

The integration of the STEM approach with local wisdom through the Ethno-STEM concept offers a relevant alternative for creating more contextual science learning. This approach connects scientific concepts with cultural practices, traditional technologies, and the potential of the local environment, enabling students to understand that science is an integral part of community life (Atmojo et al., 2025; Sumarni et al., 2022). In addition to supporting the preservation of local culture, Ethno-STEM-based learning is also aligned with the implementation of the Sustainable Development Goals (SDGs), particularly Goal 4 on Quality Education, which emphasizes the importance of inclusive, relevant, and sustainable learning.

In addition to presenting contextual learning materials, improving the quality of instruction also requires strategies that can enhance students' motivation and engagement. One strategy that has proven effective is the implementation of gamification, which refers to the use of game elements, such as points, badges, levels, challenges, and rewards, in the learning process (Jipli & Elaklouk, 2025; Li et al., 2023). Numerous studies have shown that gamification can increase learning motivation, active engagement, and create more enjoyable learning experiences without compromising the depth of conceptual understanding (Khaldi et al., 2023; Ratinho & Martins, 2023; Triantafyllou et al., 2025). To ensure that these benefits extend beyond entertainment, gamification should be integrated with the principles of deep learning, which emphasize learning experiences that are mindful, meaningful, and joyful (Anwar et al., 2023). These principles encourage students to develop a deeper understanding through reflection, exploration, and the application of knowledge in various real-world contexts (Mutmainnah et al., 2025; Zuhro et al., 2025).

Although STEM, Ethno-STEM, gamification, and deep learning have increasingly been incorporated into science education, existing studies have generally examined these approaches separately or in limited combinations (Li et al., 2019; Sumarni et al., 2022; Li et al., 2023; Atmojo et al., 2024; Mutmainnah et al., 2025). The integration of Ethno-STEM, gamification, and deep learning principles within a single digital teaching material for elementary science learning remains relatively underexplored. Moreover, existing digital teaching materials tend to emphasize content delivery and practice exercises, with less attention to integrating local cultural contexts, STEM-based activities, gamification, and deep learning principles within a unified instructional design. This gap highlights the need for digital teaching materials that bring these components together to provide contextual, interactive, and meaningful science learning experiences.

Based on these issues, this study aimed to develop the SINGA (STEM Integration of Cultural Values and Active Gamification) E-Module, which integrates the Ethno-STEM approach, gamification, and deep learning principles for science learning in elementary schools. The e-module was designed as a contextual, interactive, and student-centered digital teaching material to support more meaningful learning experiences.

METHODS

This study employed a Research and Development (R&D) approach to develop the SINGA E-Module (STEM Integration of Cultural Values and Active Gamification). This digital teaching material integrates the Ethno-STEM approach, gamification, and deep learning principles for science learning in elementary schools. The developed product was designed as a contextual, interactive, and student-centered digital teaching material by integrating local cultural values into science learning.

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The development process followed the 4D (Four-D) model proposed by Thiagarajan, Semmel, and Semmel (1974), which consists of four stages: Define, Design, Develop, and Disseminate. However, this study was limited to the Define, Design, and Develop stages because its primary objective was to produce a valid and practical product. The Disseminate stage was not conducted and is recommended for future research.

The limited practicality test was conducted at SDN 105 Pekanbaru in July 2026 and involved five elementary school teachers and 15 fifth-grade students. The implementation procedure consisted of needs analysis, product design, expert validation, product revision, and limited practicality testing.

During the Define stage, a needs analysis was conducted to identify problems in elementary school science learning, students' characteristics, curriculum requirements, and the need for digital teaching materials integrating Ethno-STEM, gamification, and deep learning principles. The needs analysis was carried out through classroom observations, teacher interviews, and an analysis of curriculum documents and teaching materials used in schools.

The Design stage aimed to develop the initial prototype of the SINGA E-Module. At this stage, the learning outcomes, learning objectives, instructional content, Ethno-STEM-based learning activities, gamification elements, assessment instruments, and the e-module interface were designed. All components were developed based on the principles of deep learning, namely mindful learning, meaningful learning, and joyful learning, to provide students with more meaningful and contextual learning experiences.

The Develop stage included expert validation and practicality testing. Expert validation was conducted to evaluate the validity and appropriateness of the product before its implementation. The validation process involved a subject matter expert, a media expert, and a cultural expert, who assessed the content and language, presentation, media design, and integration of local cultural values within the e-module.

The three experts were selected purposively based on their academic qualifications, relevant expertise, and professional experience. The subject matter expert was selected based on expertise in elementary science education and science learning. The media expert was selected based on expertise in educational technology and digital learning media. The cultural expert was selected based on expertise in local culture and experience in integrating local cultural values into educational contexts. These selection criteria ensured that the e-module was evaluated from the perspectives of content accuracy, digital media quality, and the appropriateness of local cultural integration. Feedback and suggestions from the validators were used as the basis for revising and improving the product.

After being declared valid, the SINGA E-Module underwent a limited practicality test at SDN 105 Pekanbaru in July 2026, involving five elementary school teachers and 15 fifth-grade students. The practicality test aimed to evaluate the ease of use, visual attractiveness, clarity of content presentation, ease of navigation, and usefulness of the e-module in supporting science learning.

The research instruments consisted of expert validation sheets and practicality questionnaires using a four-point Likert scale. The validation sheets were used to assess content and language appropriateness, presentation, graphical design, and the suitability of the integration of Ethno-STEM, gamification, and deep learning principles. Meanwhile, the practicality questionnaires were used to obtain teachers' and students' responses regarding the ease of use, efficiency, attractiveness, and usefulness of the SINGA E-Module during the learning process.

The research data were analyzed using descriptive quantitative analysis. The validation and practicality scores were calculated as percentages. Furthermore, the percentage scores were interpreted based on validity and practicality criteria to determine the levels of product validity and practicality. The SINGA E-Module was considered to have acceptable validity if it achieved a valid or very valid category based on the expert validation results and acceptable practicality if it achieved a practical or very practical category based on the practicality test results.

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RESULTS AND DISCUSSION

Define Stage

The define stage aimed to identify the requirements for developing the SINGA E-Module through curriculum analysis, teacher needs analysis, student needs analysis, and an analysis of the local cultural context of Riau. The findings from this stage served as the foundation for determining the design, content, and characteristics of the developed e-module.

Curriculum Analysis

The curriculum analysis was conducted based on the Learning Outcomes (Capaian Pembelajaran/CP) for Science (IPAS) Phase C under the Merdeka Curriculum. The analysis indicated that fifth-grade science learning emphasizes students' ability to understand scientific concepts through observation, investigation, problem-solving, and the application of scientific concepts to everyday life.

The learning materials selected for the development of the SINGA E-Module included ecosystems, the water cycle, the properties of light, and the properties of sound. These topics were selected because they are closely related to everyday phenomena, making them highly suitable for integration with the Ethno-STEM approach, simple project-based learning activities, and the local cultural context of Riau.

However, the analysis of existing instructional materials revealed that science content is still primarily presented conceptually through textbooks, providing limited opportunities for students to explore, investigate, and relate scientific concepts to their surrounding environment. Therefore, there is a need for digital teaching materials that provide more contextual, interactive, and student-centered learning experiences.

Teacher Needs Analysis

The teacher needs analysis was conducted through classroom observations and interviews with fifth-grade elementary school teachers. The interview results revealed that the primary learning resources used in science instruction were government-issued textbooks, supplemented by oral explanations and occasional use of simple presentation media.

Teachers reported that although the available textbooks are aligned with the curriculum, the content is predominantly text-based and therefore less effective in capturing students' attention. Furthermore, the existing teaching materials provide limited learning activities that encourage students to conduct scientific investigations, think critically, or connect scientific concepts with their local environment and culture.

Teachers also noted that students demonstrated greater enthusiasm when learning involved digital media, videos, and interactive activities. Therefore, teachers expressed the need for digital teaching materials that are easy to use, visually engaging, incorporate Ethno-STEM-based learning activities, and include gamification elements to enhance student engagement throughout the learning process.

Student Needs Analysis

Classroom observations showed that students were more actively engaged when teachers used media containing images, videos, and interactive activities than when instruction relied solely on textbooks. Most students reported that they preferred learning activities involving games, quizzes, challenges, and rewards upon completing learning tasks.

In the topics of ecosystems, the water cycle, light, and sound, several students experienced difficulties in connecting scientific concepts with phenomena encountered in their daily lives. Instruction that focused primarily on content delivery led students to memorize concepts rather than develop an understanding of the scientific processes occurring in their surrounding environment.

These findings indicate that students require digital teaching materials capable of presenting scientific concepts in a more concrete, visual, and contextual manner through illustrations, videos, simple simulations, inquiry-based activities, and educational games that can enhance learning motivation.

Analysis of the Local Cultural Context of Riau

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The analysis of the local cultural context was conducted to identify local cultural resources that could be integrated into science learning. The findings revealed that Riau Province possesses various local potentials relevant to fifth-grade science topics, including the Siak River, peat forests, mangrove forests, Malay culture, traditional Malay houses, traditional games, and the utilization of natural resources by local communities.

These local phenomena can serve as meaningful learning contexts for topics such as ecosystems, the water cycle, light, and sound, enabling students to understand scientific concepts more easily through experiences closely related to their daily lives. However, observations of existing teaching materials indicated that the examples provided remain largely generic and make limited use of Riau's local potential as a learning resource. Therefore, integrating local culture into the SINGA E-Module is expected to make learning more contextual while fostering students' appreciation of their local environment and cultural heritage.

Design Stage

The design stage aimed to produce the initial design (Prototype I) of the SINGA E-Module based on the needs analysis conducted during the define stage. All components of the e-module were designed to support contextual, interactive, and student-centered science learning through the integration of the Ethno-STEM approach, gamification, and deep learning principles. This stage involved developing the learning sequence, selecting instructional content, designing learning activities, and creating a user interface appropriate for the characteristics of elementary school students.

The instructional content was developed in accordance with the Learning Outcomes (Capaian Pembelajaran/CP) for Science (IPAS) Phase C under the Merdeka Curriculum, covering the topics of ecosystems, the water cycle, the properties of light, and the properties of sound. Each topic was systematically organized, beginning with an introductory activity, followed by concept presentation, Ethno-STEM-based learning activities, practice exercises, interactive quizzes, and learning evaluation. In addition, each topic was connected to the local cultural context of Riau, enabling students to relate scientific concepts to phenomena encountered in their daily lives.

Gamification was incorporated through challenge-based activities, interactive quizzes, and immediate feedback provided after students completed each learning activity. These activities were designed based on the principles of deep learning (mindful learning, meaningful learning, and joyful learning), so that the learning process would not only focus on conceptual understanding but also encourage students to think critically, solve problems, and reflect on their learning experiences.

The design stage resulted in Prototype I of the SINGA E-Module, which consisted of a cover page, user guide, learning outcomes, learning objectives, instructional materials, Ethno-STEM activities, instructional videos, educational games, interactive quizzes, evaluation activities, references, and the developer's profile. The e-module was developed with an attractive interface using a combination of illustrations, icons, colors, and interactive multimedia to suit the characteristics of elementary school students. Several screenshots of the initial prototype of the SINGA E-Module developed during the design stage are presented in Figure 1.

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Figure 1. Interface of the SINGA E-Module

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Develop Stage

The develop stage aimed to produce the SINGA E-Module as a feasible digital teaching material for science learning in elementary schools. At this stage, the e-module was validated by three experts, consisting of a subject matter expert, a media expert, and a cultural expert. Each validator conducted two rounds of evaluation. The first validation aimed to identify the shortcomings of the product so that revisions could be made. In contrast, the second validation was conducted to ensure that all revisions had addressed the validators' suggestions and that the product met the established feasibility criteria. After all validators confirmed that the product was suitable for use, the SINGA E-Module underwent a practicality test involving elementary school teachers and students.

Subject Matter Expert Validation

The subject matter expert validation aimed to evaluate the suitability of the SINGA E-Module in terms of its alignment with the learning outcomes, the accuracy of scientific concepts, the appropriateness of the learning activities, and the completeness of the assessment components. The validation was conducted in two stages: the first validation and the second validation after the product had been revised based on the validator's feedback.

Table 1. Results of the Subject Matter Expert Validation

Validation Stage	Obtained Score	Maximum Score	Percentage	Category
Validation I	89	115	77.39%	Valid
Validation II	103	115	89.57%	Very Valid

Based on the results of the first validation, the subject matter expert provided several suggestions to improve the content of the SINGA E-Module. The revisions included refining the presentation of scientific concepts, adding examples that were more closely related to students' local environment, improving the Ethno-STEM learning activities, and revising several assessment items to better align with the learning objectives.

After all revisions had been completed, the product underwent a second round of validation. The results of the second validation showed an improvement compared with the first validation. The validator concluded that the instructional content was well aligned with the learning outcomes, demonstrated accurate scientific concepts, and systematically integrated the Ethno-STEM approach with deep learning principles. Therefore, the SINGA E-Module was categorized as very valid in terms of content.

Media Expert Validation

The media expert validation aimed to evaluate the quality of the interface, user interface design, navigation, typography, illustrations, and multimedia functions of the SINGA E-Module. The evaluation was conducted in two stages to ensure the quality of the developed media.

Table 2. Results of the Media Expert Validation

Validation Stage	Obtained Score	Maximum Score	Percentage	Category
Validation I	74	100	74.00%	Valid
Validation II	93	100	93.00%	Very Valid

During the first validation, the media expert provided several suggestions, including improving color consistency, increasing the font size on several pages, refining the layout of images, enhancing the clarity of navigation buttons, and improving the quality of several illustrations to suit the characteristics of elementary school students better.

After the recommended revisions had been implemented, the second validation demonstrated a significant improvement in the quality of the e-module. The validator concluded that the SINGA E-Module featured an attractive interface, was easy to operate, provided clear navigation, and effectively supported the

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learning process.

Cultural Expert Validation

The cultural expert validation was conducted to evaluate the appropriateness of integrating Riau's local culture into the instructional content and the suitability of presenting cultural values alongside scientific concepts.

Table 3. Results of the Cultural Expert Validation

Validation Stage	Obtained Score	Maximum Score	Percentage	Category
Validation I	81	100	81.00%	Very Valid
Validation II	94	100	94.00%	Very Valid

During the first validation, the cultural expert provided several suggestions regarding the selection of local cultural examples, the refinement of Malay cultural terminology, and the inclusion of additional information about Riau's environmental potential to make the content more representative. In addition, the validator recommended that several learning activities place greater emphasis on the relationship between scientific concepts and the cultural practices of the local community.

After the revisions had been completed, the results of the second validation indicated an improvement in the quality of cultural integration within the SINGA E-Module. The validator concluded that the local cultural elements were presented accurately, were relevant to the instructional content, and effectively strengthened the implementation of Ethno-STEM-based learning.

Overall, the validation results demonstrated an improvement in the quality of the SINGA E-Module after revisions were made based on the validators' feedback. A comparison of the results from the first and second validation rounds for each aspect is presented in Figure 1.

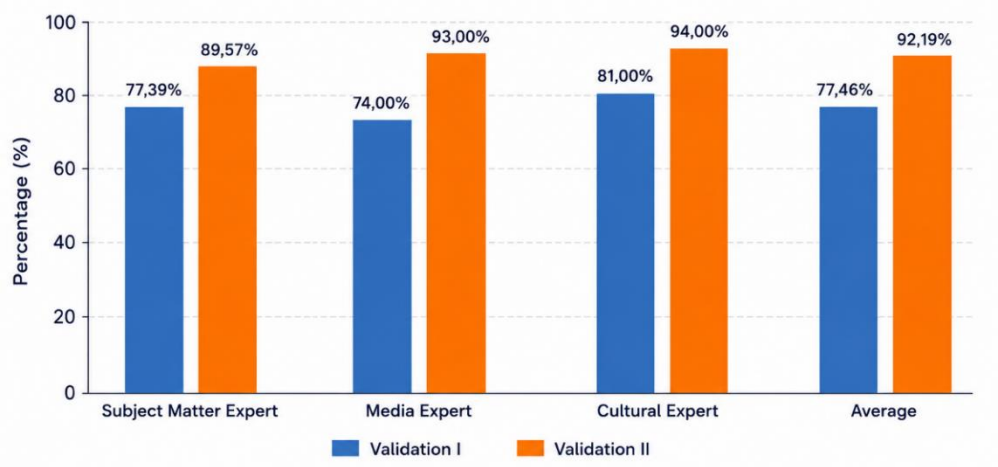

Figure 1. Summary of the Validators' Evaluation Results

These results indicate that each evaluation aspect improved after the revisions were made based on the validators' recommendations. Therefore, the SINGA E-Module met the criteria for very high validity and was considered suitable for proceeding to the practicality testing stage.

Teacher Practicality Test

After the SINGA E-Module had been validated by the experts and revised based on their feedback, the next stage was the practicality test. The practicality test aimed to evaluate the ease of use, clarity of content presentation, attractiveness of the interface, and usefulness of the SINGA E-Module in supporting science

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learning in elementary schools. The practicality test involved five fifth-grade elementary school teachers who had used the SINGA E-Module during science (IPAS) instruction. The results of the teacher's practicality evaluation are presented in Table 4.

Table 4. Results of the Teacher Practicality Test

Teacher	Ease of Use	Clarity of Content	E-Module Interface	Navigation	Usefulness	Average	Category
Teacher 1	88.00%	92.00%	90.00%	85.00%	95.00%	90.00%	Very Practical
Teacher 2	84.00%	88.00%	95.00%	90.00%	90.00%	89.40%	Very Practical
Teacher 3	92.00%	84.00%	85.00%	80.00%	90.00%	86.20%	Very Practical
Teacher 4	96.00%	96.00%	100.00%	95.00%	95.00%	96.40%	Very Practical
Teacher 5	88.00%	92.00%	95.00%	90.00%	85.00%	90.00%	Very Practical
Average	**89.60%**	**90.40%**	**93.00%**	**88.00%**	**91.00%**	**90.40%**	**Very Practical**

Based on the practicality test results, the teachers provided positive responses to the use of the SINGA E-Module. They reported that the e-module was easy to use during classroom instruction, featured an attractive interface, and helped present the instructional content more systematically and contextually. The integration of the Ethno-STEM approach with gamification activities was perceived to enhance students' engagement throughout the learning process. Furthermore, the implementation of deep learning principles through activities involving observation, exploration, discussion, and reflection was considered effective in encouraging students to learn more actively and meaningfully.

Student Practicality Test

In addition to involving teachers, the practicality test was also conducted with 15 fifth-grade elementary school students to evaluate users' responses to the SINGA E-Module. The evaluation was carried out after the students had used the e-module to learn the topics of ecosystems, the water cycle, the properties of light, and the properties of sound. The evaluated aspects included ease of use, interface design, clarity of the instructional content, learning activities, and students' interest in the e-module. The results of the student practicality test are presented in Table 5.

Table 5. Results of the Student Practicality Test

Evaluation Aspect	Percentage	Category
Ease of use	88.67%	Very Practical
Clarity of content	86.33%	Very Practical
E-module interface	95.00%	Very Practical
Gamification activities	91.67%	Very Practical
Learning motivation	89.33%	Very Practical
Overall Average	**90.20%**	**Very Practical**

The practicality test results indicated that the students responded very positively to the use of the SINGA E-Module. They reported that the e-module was easy to use, featured an attractive interface, and helped them understand the learning materials through illustrations, videos, Ethno-STEM activities, and interactive quizzes. In addition, gamification elements such as points, badges, and challenges made the learning process more enjoyable and increased students' motivation to complete each learning activity.

The findings indicate that the developed SINGA E-Module achieved a very valid category based on evaluations by the subject matter, media, and cultural experts. The improvement in validation scores from the first to the second round demonstrates that revisions based on the validators' feedback successfully enhanced the overall quality of the product. This finding confirms that expert validation is a crucial stage in research and development to ensure the feasibility of educational products (Thiagarajan, 1974; Sugiyono, 2019).

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The high content validity indicates that the SINGA E-Module is well aligned with the Learning Outcomes (CP) for Science (IPAS) Phase C, presents scientifically accurate concepts, and effectively integrates the Ethno-STEM approach with deep learning principles. Presenting scientific concepts systematically and in relation to students' real-life experiences facilitates meaningful conceptual understanding and strengthens scientific literacy (Kusumaningtyas et al., 2025; Lederman et al., 2013). Likewise, improvements in the interface, typography, illustrations, and navigation resulted in a more attractive and user-friendly digital learning resource, which can enhance students' engagement and learning effectiveness (Nurjanah et al., 2025; Okasha, 2025; Cromley & Chen, 2025).

The cultural expert validation also showed that the integration of Riau Malay cultural contexts into the topics of ecosystems, the water cycle, light, and sound was accurate and relevant. Integrating local culture into science learning not only supports conceptual understanding but also strengthens cultural identity and environmental awareness while making learning more contextual (Rafiuddin et al., 2024; Sakti et al., 2024; Setiawan et al., 2017).

The practicality test demonstrated that the SINGA E-Module was categorized as very practical by both teachers and students. Teachers reported that the e-module was easy to use, well organized, visually appealing, and useful for supporting science instruction. They also noted that the integration of Ethno-STEM activities and gamification increased students' participation during learning, indicating that the e-module can be readily implemented in elementary classrooms (Nieveen, 1999). Similarly, students responded positively to the e-module, particularly its visual design, multimedia features, and gamification elements, such as quizzes, challenges, points, and badges, which increased learning motivation and engagement (Jipli & Elaklouk, 2025; Triantafyllou et al., 2025),

Another strength of the SINGA E-Module is the implementation of deep learning principles through observation, exploration, discussion, problem-solving, and reflection. These activities promote mindful, meaningful, and joyful learning, encouraging students to develop a deeper understanding of scientific concepts and apply them in real-life contexts. This approach is consistent with current educational transformation efforts aimed at fostering critical thinking, problem-solving, creativity, and scientific literacy as essential 21st-century competencies (Fullan et al., 2018; OECD, 2023).

Overall, the findings demonstrate that the SINGA E-Module fulfills the two essential quality criteria of educational product development, validity and practicality. By integrating the Ethno-STEM approach, gamification, and deep learning principles, the e-module provides a contextual, interactive, and meaningful digital learning resource that has the potential to enhance the quality of elementary science education and strengthen students' scientific literacy.

CONCLUSION AND RECOMMENDATIONS

The SINGA E-Module, which integrates the Ethno-STEM approach, gamification, and deep learning principles, was successfully developed as a digital teaching material for science (IPAS) learning in elementary schools. The results showed that the developed e-module met the criteria for very high validity, with validation scores of 89.57% for content, 93.00% for media, and 94.00% for cultural integration. In addition, the SINGA E-Module was categorized as very practical, with an average practicality score of 90.40% based on teachers' evaluations and 90.20% based on students' evaluations. These findings indicate that the e-module contains content aligned with the learning outcomes, features an attractive interface, is easy to use, and effectively integrates the local cultural context through Ethno-STEM activities, gamification, and meaningful learning experiences. Therefore, the SINGA E-Module is suitable for use as a digital teaching material to support more contextual, interactive, and student-centered science (IPAS) learning in elementary schools. Future research is therefore recommended to investigate whether the SINGA E-Module has the potential to support improvements in students' scientific literacy through experimental or quasi-experimental studies involving larger and more diverse samples and educational settings.

Credit authorship contribution statement
Mitha Dwi Anggriani: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft, Project administration. Riza Andriani: Supervision, Methodology, Writing – review & editing. Ilfi Intansari: Supervision, Resources, Writing – review & editing.

Declaration of competing interest
The authors declare no potential conflicts of interest.

Data Availability
The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical Statement
This study was conducted in accordance with ethical guidelines for educational research involving human participants. Prior to data collection, teachers and elementary school students were informed about the purpose and procedures of the study. Informed consent was obtained from all teacher participants and, where applicable, from the parents or legal guardians of the students. Participation was voluntary, and the confidentiality and anonymity of all participants were maintained throughout the study.

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