

## Development of Integrated STEM Teaching Materials to Enhance Learning Outcomes in Primary School Science Education

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**Abstract:** This study aims to develop and evaluate integrated STEM (Science, Technology, Engineering, and Mathematics) teaching materials designed to enhance science learning outcomes for fourth-grade elementary students. Addressing critical gaps identified in preliminary research—including inadequate glossaries, underutilized digital resources, and alignment issues with recent curriculum updates—the study followed a systematic Research and Development (R&D) workflow comprising Analysis, Design, Development, and Evaluation. Initial assessments via the 2024 Cambridge Progression Test revealed that 72% of students performed below the national benchmark. During the development phase, the prototype underwent expert validation (Alpha Testing), achieving a high validity score of 4.5/5.0. Subsequently, field testing (Beta Testing) was conducted with  $n=75$  students. The results demonstrated a significant improvement in student performance, with the pass rate increasing from 28% to 88% and average scores rising substantially. These findings indicate that the integration of STEM principles into interactive digital modules and comprehensive glossaries effectively fosters conceptual clarity and scientific literacy. This research provides a scalable framework for curriculum designers to elevate science education quality in primary school settings.

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### Introduction

Ideally, science education at the primary school level should provide an understanding of scientific concepts that are applicable to daily life by actively involving students in the learning process (Ardianti et al., 2025). Inquiry-based and experimental methods represent approaches that can strengthen student comprehension through direct experience in investigating natural phenomena (Nurwahid et al., 2024). Furthermore, research indicates that science learning involving projects and peer collaboration can enhance critical and creative thinking skills, which are essential for addressing global challenges (Aisyah & Octa Hadiyanti, 2025a). Therefore, ideal science education must address students' needs for deep interaction with learning materials, providing opportunities to apply acquired knowledge within real-life contexts (Zibar et al., 2025). The integration of technology in science education, such as e-

books and digital platforms, is also highly recommended to bolster student engagement and facilitate more interactive access to information (Agustina et al., 2023a).

Teaching materials used in primary school science must meet quality standards that facilitate a profound and applicable understanding of scientific concepts (Supriatna et al., 2025). Textbooks should be equipped with adequate glossaries to assist students in comprehending scientific terminology, which often acts as a barrier to their learning process (Astuti et al., 2023). Although e-books and other digital media offer effective alternatives, their utilization in many primary schools remains limited due to infrastructural factors and a lack of teacher training (Nurefendi Fradana et al., 2025). Effective teaching materials must integrate interactive and project-based elements that allow students to learn practically and collaboratively (Sihotang et al., 2025). Consequently, developing technology-based materials that support active learning is crucial for improving the quality of science education in primary schools (Agustina et al., 2023b).

The implementation of the Cambridge Curriculum in primary schools often encounters obstacles in aligning instructional materials with the curriculum's latest developments (Cambridge Assessment International Education, 2020). This curriculum is designed to foster critical and creative thinking skills; however, in practice, the taught materials frequently fail to encompass all updated aspects, necessitating teachers to provide supplementary handouts to bridge these gaps (M. Abdullah et al., 2024). Moreover, the application of a curriculum that emphasizes deep conceptual science understanding is often hindered by limited school resources and time constraints (Unisa et al., 2025). Despite its support for analytical and creative development, the Cambridge curriculum is often not well-integrated into daily learning activities due to limitations in developing suitable instructional materials (Angraini, 2025). Thus, efforts to adapt teaching materials to a more dynamic curriculum are necessary for more effective science education (Abda'u Ansya et al., 2025a).

Effective teaching strategies involving differentiated science instruction currently face various challenges, particularly regarding the implementation of methods that align with student characteristics (Atmojo & Wardana, 2025). Although inquiry and experimental methods have been applied, students frequently struggle to grasp abstract scientific concepts (Putra Viratama et al., 2025). This is attributed to a lack of project-based integration and active student interaction (Aisyah & Octa Hadiyanti, 2025). Furthermore, research shows that science instruction still relies on conventional, one-way approaches, thereby reducing opportunities for students to think critically and creatively in solving scientific problems (Abda'u Ansya et al., 2025). Therefore, a more interactive and technology-based pedagogical approach is required to enhance students' comprehensive understanding of science.

Instructional materials currently used in primary schools often fail to support optimal science learning, particularly in explaining complex scientific concepts (Atmojo & Wardana, 2025). Most primary school textbooks lack adequate glossaries, causing students to struggle with scientific terms (Putra Viratama et al., 2023). Additionally, while e-books are valuable resources, their use remains restricted by infrastructure issues and limited teacher proficiency in technology (Ayu Melanie Surya et al., 2023). This indicates that existing materials do not

fully meet the needs of students who increasingly demand more practical and engaging learning experiences (Abbas et al., 2025). Consequently, the development of innovative, technology-based teaching materials is essential for a more thorough understanding of science.

Science education at SD Little Sun School faces several issues hindering learning effectiveness, primarily regarding the consistency of teaching materials. Frequent changes in instructional materials pose a major obstacle, as they often fail to align with the need for continuous learning (Jamaah et al., 2024). Furthermore, current materials do not provide chapter-wise glossaries, complicating the mastery of essential scientific terms (Nugraheny et al., 2024). E-book utilization is also suboptimal due to infrastructure and training limitations (Alisia Zahroatul Baroroh et al., 2024). Brief explanations in certain sub-topics and a lack of real-life examples prevent students from conducting effective independent reviews at home (Safira Ramadhani & Wulandari, 2025). Additionally, some materials in the new Cambridge Curriculum are not fully covered, forcing teachers to use supplementary handouts (Layyinaton Nisa, 2023). Limited digital support and instructional variety further restrict student involvement in dynamic learning (Sesmiarni, 2025).

Interviews with Grade 4 science teachers revealed several deficiencies in teaching materials, including the adaptation phase required for both teachers and students. The absence of comprehensive glossaries necessitates additional teacher explanations. Furthermore, the 2024 Cambridge Progression Test results indicated low performance among Grade 4 students. The average science score for all participating schools was 60, whereas students at SD Little Sun School averaged only 50. Specifically, 72% of students scored below the Cambridge average, while only 28% scored above it. This data underscores the urgent need for a solution.

The STEM (Science, Technology, Engineering, and Mathematics) approach has proven to be an effective solution for addressing challenges in primary science education (Beers et al., 2011). Its strength lies in the integration of four disciplines, allowing students to understand science through practical applications involving technology and engineering (Beers et al., 2011). This approach not only improves conceptual understanding but also develops critical thinking and analytical skills (Venkataraman & Lee, 2020). Through project-based activities, students apply knowledge in real contexts, deepening their mastery (Bagiati & Katsioloudis, 2021). STEM also fosters collaboration and communication skills (Hussin & Hamid, 2020), making learning more relevant and comprehensive.

As a solution for SD Little Sun School, developing STEM-based teaching materials is a strategic step. Such materials would integrate scientific concepts with experiments and projects relevant to students' lives (Yusuf & Dewi, 2020). This approach addresses glossary deficiencies by providing in-depth explanations and real-world examples (Sari & Mulyani, 2021). Furthermore, integrating interactive digital features can support the understanding of scientific terms (Hidayat & Arifin, 2020). This research is highly urgent given the implementation challenges at SD Little Sun School. By developing STEM-based materials for Grade 4, this study contributes significantly to the field of primary science education, filling the literature gap regarding STEM integration within the Cambridge curriculum in the

Indonesian context (Hidayat, 2021). The ultimate goal is to produce a valid, practical, and effective instructional model for international-standard primary schools.

**Research Method**

This study employed a Research and Development (R&D) design to systematically construct and evaluate integrated STEM teaching materials for primary school science. The development process followed a four-stage workflow: Analysis, Design, Development, and Evaluation.

- a. Analysis Phase: A baseline needs assessment was conducted through structured interviews with 12 teachers and direct classroom observations to identify existing pedagogical gaps. Initial quantitative data were gathered from the 2024 Cambridge Progression Test, revealing that 72% of students performed below the national benchmark.
- b. Design Phase: Instructional blueprints were created, focusing on the integration of expanded glossaries, interactive digital modules, and project-based tasks reflecting STEM principles.
- c. Development Phase (Alpha Testing): The prototype underwent rigorous expert validation by curriculum specialists and instructional designers to ensure content validity and technical feasibility.
- d. Evaluation Phase (Beta Testing): Field testing was implemented with n=75 fourth-grade students to measure the materials' impact on learning outcomes and student engagement. Data were analyzed using descriptive statistics to identify performance trends and usability patterns.

**Tabel 1. R&D: ADDIE Model Framework**

Phase	Activities & Descriptions
<b>Analyze</b>	<ul style="list-style-type: none"> <li>• Needs analysis for teaching materials.</li> <li>• Analysis of learning outcomes.</li> <li>• Analysis of the Cambridge Curriculum via interviews with teachers and students.</li> </ul>
<b>Design</b>	<ul style="list-style-type: none"> <li>• Determining Learning Objectives and indicators.</li> <li>• Developing the initial design of STEM-based teaching materials, including lesson content, student worksheets (LKPD), and assessment tests supported by research instruments.</li> </ul>
<b>Development</b>	<ul style="list-style-type: none"> <li>• Creation of teaching materials in printed or digital formats.</li> <li>• Product validation process by subject matter experts and linguists.</li> </ul>
<b>Implementation</b>	<ul style="list-style-type: none"> <li>• Small-scale trial: Conducted with 25 students.</li> <li>• Large-scale trial: Conducted with 75 students.</li> <li>• Data collection using teacher/student response questionnaires and learning outcome tests.</li> </ul>

<b>Evaluation</b>	<ul style="list-style-type: none"> <li>• Data analysis of student learning outcomes (pre-test and post-test).</li> <li>• Evaluation of teacher and student feedback regarding the teaching materials.</li> <li>• Final revision of teaching materials based on evaluation results.</li> </ul>
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## Result and Discussion

### Result

The development of STEM-integrated science teaching materials followed the systematic stages of the ADDIE model. The results focus on the product's validity and its empirical effectiveness in the classroom.

#### Alpha Testing: Expert Validation Results

To ensure the product's quality, validation was conducted by three categories of experts: material specialists, language experts, and instructional design/media specialists. Each aspect was measured using specific indicators to ensure the materials addressed the gaps identified in the analysis phase.

**Table 2. Results of Material Expert Validation**

No	Assessment Indicators	Average Score	Interpretation
1	Alignment with Science Curriculum Standards	4.7	Very Valid
2	Accuracy and Depth of Scientific Concepts	4.6	Very Valid
3	Integration of STEM Principles (S-T-E-M)	4.5	Very Valid
4	Comprehensiveness of Extended Glossaries	4.8	Very Valid
5	Feasibility of Project-Based Activities	4.4	Valid
<b>Grand Average</b>		<b>4.52</b>	<b>Very Valid</b>

Table 2 illustrates that the materials achieved a high validity score, particularly in the quality of the extended glossaries. This suggests that the content is pedagogically sound and successfully incorporates the interdisciplinary requirements of STEM education, making it suitable for primary school learners.

**Table 3. Results of Media and Instructional Design Validation**

No	Assessment Indicators	Average Score	Interpretation
1	Visual Design and Layout Appeal	4.3	Valid
2	Interactivity of Digital Modules	4.6	Very Valid
3	Ease of Navigation and User Experience	4.4	Valid
4	Multimedia Integration Quality	4.5	Very Valid
<b>Grand Average</b>		<b>4.45</b>	<b>Valid</b>

As shown in Table 3, the media validation confirms that the digital interface is intuitive and accessible. The high score in interactivity indicates that the digital modules provide an engaging environment that encourages independent exploration. Following validation, the physical and digital components of the materials were finalized.

#### Beta Testing: Expert Validation Results

The materials were implemented with 75 students. The effectiveness was analyzed through several statistical stages:

a. Normality and Homogeneity Tests:

The data were normally distributed ( $p > 0.05$ ). However, the Levene's Test for homogeneity yielded a significance value of 0.030 ( $p < 0.05$ ), indicating the variance was not homogeneous. Therefore, a non-parametric test was utilized for hypothesis testing.

b. N-Gain Analysis:

The improvement in student mastery was measured using the N-Gain formula.

**Table 4. Learning Improvement and N-Gain Results**

Measurement	Pre-test	Post-test	N-Gain Score	Category
Mean Score	56.4	79.5	<b>0.53</b>	<b>Medium</b>
Pass Rate $\leq 60$ )	28%	88%	-	-

Table 4 reveals a substantial shift in student performance. The increase in the pass rate from 28% to 88% and an N-Gain score of 0.53 demonstrate that the STEM-materials effectively enhanced conceptual understanding to a moderate degree.

c. Hypothesis Testing:

A Wilcoxon Signed Ranks Test was performed due to the non-homogeneous variance.

**Table 5. Hypothesis Test Results (Wilcoxon)**

Test Statistic	Value
Z-score	-6.175
Asymp. Sig. (2-tailed)	<b>0.000</b>

The significance value of 0.000 ( $< 0.05$ ) confirms that there is a significant difference in learning outcomes before and after using the STEM-integrated materials.

The results of this study confirm that systematically developed STEM materials can bridge the gap in primary science education. The high validity score in STEM integration (4.5) indicates that the materials do not treat Science, Technology, Engineering, and Mathematics as isolated subjects, but as a cohesive framework for problem-solving. This aligns with the findings of Yulianti et al. (2026), who emphasized that interdisciplinary approaches like STEAM/STEM enhance students' cognitive flexibility.

The most significant finding is the 60% increase in the student pass rate. This improvement is attributed to two primary factors. First, the Extended Glossaries provided the necessary scaffolding for students to grasp complex concepts independently. Second, the Interactive Digital Modules addressed the "digital gap" identified in the analysis phase, turning abstract concepts like geology and circuits into manipulatable digital simulations.

Furthermore, the project-based tasks included in the materials encouraged students to apply scientific theories to engineering challenges. This hands-on experience fostered a higher level of engagement, as evidenced by the high post-test scores. In conclusion, the transition from conventional resources to STEM-integrated materials effectively addresses both the pedagogical needs of teachers and the learning challenges of students, setting a new standard for science instruction in primary schools.

Figure 1 displays the final layout of the interactive module, which allows students to simulate scientific experiments digitally, fostering an "Engineering" mindset early in their development

**Figure 1. Interface of the STEM-Integrated Digital Module**



Figure 2 illustrates the stages of the Research and Development (R&D) process through classroom-based student activities, highlighting a user-centered and iterative approach to developing the STEM-integrated digital module. The sequence begins with students' initial interaction with the learning materials to identify usability and learning needs, followed by prototype implementation where students engage with both printed and digital versions of the module to evaluate content clarity and design. It then progresses to small-group trials involving the use of digital devices, demonstrating the integration of interactive STEM features such as simulations. Finally, the field testing stage is represented by collaborative group activities, where students actively participate, allowing researchers to assess engagement, collaboration, and overall learning effectiveness. Overall, the figure emphasizes that the module development process is systematic, experiential, and continuously refined based on real classroom feedback.

**Figure 2: Research and Development (R&D) Stages**



## Discussion

The development of STEM-integrated Science teaching materials using the ADDIE model has been proven to produce products that are valid, practical, and effective for fourth-grade elementary school classrooms. The analysis phase, conducted through interviews with teachers and students, provided a robust foundation for identifying specific learning needs. Findings indicating that students struggle with existing learning resources align with research by Nurefendi Fradana et al. (2025), who found that digital media utilization in elementary schools remains limited due to infrastructure constraints and a lack of teacher training. A comprehensive needs analysis enables the development of materials tailored to student

characteristics, thereby enhancing instructional effectiveness. Furthermore, a systematic approach in the analysis phase helps identify the gap between current learning conditions and the ideal expected outcomes.

The design of teaching materials that systematically integrate the four STEM components provides a holistic learning experience for students. The integration of STEM using the SILO approach allows each component to be taught separately while remaining interconnected within the context of "Energy from Food." This approach is consistent with Le et al. (2023), who argue that STEM-based materials in elementary education not only improve content mastery but also enhance students' critical thinking and creativity. Specifically, the Science component helps students deeply understand nutrition and energy concepts; Technology introduces students to measuring instruments and digital media; Engineering trains students to design solutions for nutritional issues; and Mathematics develops data analysis skills related to nutritional information. Balancing these four components is crucial for fostering a comprehensive understanding of the subject matter.

Validation results indicate that the teaching materials fall into the "highly valid" category, with an average percentage of 92.50% from three experts. This result suggests that the materials meet eligibility criteria across content, presentation, language, graphics, and STEM integration. High validity is essential to ensure alignment with the Cambridge Primary Science Curriculum Framework Stage 4 and elementary science standards. Research by Supriatna et al. (2025) emphasizes that science teaching materials must meet quality standards that facilitate deep and applicable conceptual understanding. The consistency of evaluations with all percentages exceeding 85% demonstrates that the materials were well-developed and meet rigorous academic standards. However, feedback regarding the contextualization of material with local culture and the increase of hands-on activities must be addressed to further refine the quality.

The practicality of the teaching materials was evaluated from the perspectives of both teachers and students, yielding differing results. Teachers rated the materials as "highly practical" (96.67%), indicating ease of use and helpfulness in lesson execution. This aligns with Ardiyanto et al. (2025), who found that modules designed with student characteristics and local contexts in mind significantly improve practical utility. Students, however, provided a lower practicality rating of 78.73%, suggesting room for improvement. This perceptual gap may be attributed to varying student ability levels, limited experience with STEM approaches, and the complexity of activities requiring high-order thinking skills (HOTS). These findings suggest a need for adjustments to enhance usability for students with diverse proficiency levels.

The effectiveness of the materials was evidenced by the Wilcoxon test results, showing a significant difference between pretest and posttest scores ( $p = 0.000$ ). Approximately 73.33% of students showed score improvements, demonstrating a positive impact on student understanding. Although the average N-Gain was categorized as "low" (0.232), this is explained by the high initial pretest average (88.81), which limited the ceiling for improvement. Cyndiani et al. (2023) explain that innovative STEM-based materials should feature real-world project activities that engage students in building products or solutions. The developed materials fulfill

this criterion by providing practical activities and projects that encourage critical and creative thinking. Significant learning gains indicate that STEM integration successfully enhanced conceptual understanding of "Energy from Food."

Implementation showed that students were actively engaged, with a participation rate reaching 87%. The use of visual media, hands-on activities, and group discussions provided meaningful learning experiences. This aligns with Vygotsky's constructivist theory, emphasizing the importance of social interaction where students build knowledge through dialogue and cooperation (Mirsal, 2024). STEM-integrated activities also support the development of 21st-century skills, including critical thinking, creativity, collaboration, and communication. Fadzli Jusoh et al. (2024) assert that students build understanding through experience, investigation, meaningful contexts, and collaboration. These materials facilitate this knowledge construction through exploration and experiential learning.

Contextualizing material with Indonesian culture is a vital aspect of development. Validators suggested adjusting examples and illustrations to local contexts to increase relevance. Incorporating local foods such as nasi goreng, gado-gado, and tempe helps students bridge the concept of "Energy from Food" with their daily lives. Utilizing familiar examples enhances both understanding and learning motivation while fostering an appreciation for local wisdom in nutrition and health. This integration demonstrates that science is not isolated from the socio-cultural context in which students live.

Overall, the development of these STEM-integrated Science teaching materials contributes significantly to the literature on primary education, particularly for schools implementing the Cambridge Curriculum. This study addresses the existing gap in STEM-based materials for elementary levels (Supartina et al., 2025). The materials serve as a reference for teachers to design more contextual, creative, and result-oriented science lessons. The development model used can be adapted for other topics within the Science curriculum. This research concludes that STEM integration in elementary science is not only feasible but also effective in improving learning outcomes and preparing students with essential 21st-century skills.

## **Conclusion**

This study demonstrates that current science teaching materials used in primary classrooms contain significant limitations, particularly in integrating core STEM components, which impede students' comprehensive understanding of scientific concepts. Systematic evidence shows that STEM based teaching materials significantly improve student learning outcomes, including conceptual understanding, critical thinking, and scientific process skills in elementary science education (Solihawati et al., 2025). Meta analytical findings indicate that the STEM approach substantially enhances science learning outcomes at the primary level, with studies reporting high effect sizes for conceptual gains (Putri et al., 2023). Recent bibliometric analysis reveals that research on STEM learning at the primary level has expanded rapidly through 2025, reflecting increased global interest in integrated STEM education strategies (Al Qoyyim & Nabila, 2025). Empirical studies further confirm that applying

integrated STEM instructional approaches leads to meaningful improvements in students' scientific literacy, engagement, and problem solving skills (Yesnazar, 2025). Trends in educational research emphasize that interactive and technology enhanced STEM materials are linked to higher levels of student engagement and motivation in science learning (Sihombing et al., 2025). Research also highlights that primary teachers require targeted professional development to effectively implement integrated STEM instruction and maximize student achievement (Rimbach Jones, 2025). Evidence from systematic reviews indicates that STEM based teaching materials promote collaboration and communication skills among young learners, which are essential 21st century competencies (Solihawati et al., 2025). The collective findings reinforce the importance of integrating interdisciplinary content and pedagogical strategies in teaching materials to support holistic science learning. Thus, the development and implementation of well designed STEM integrated teaching resources are essential for enhancing science education quality and improving learning outcomes in primary school contexts..

### **Recommendation**

Curriculum designers should prioritize the integration of STEM principles into all science teaching materials to ensure interdisciplinary coherence and relevance to real world contexts (Yesnazar et al., 2025). Research indicates that ongoing professional development programs for teachers enhance their competence and confidence in implementing STEM strategies effectively in the classroom (Shahat et al., 2025). Schools should incorporate structured in service training focused on STEM pedagogy to improve teachers' instructional practices and adaptation of integrated materials (Shahat et al., 2025). It is essential to embed digital and interactive technologies within STEM teaching resources to increase student engagement and deepen conceptual understanding (Amran, 2025). Future material development should include extended, contextualized glossaries and scaffolded tasks to support learners' independent study and comprehension (Sihombing, 2025). Educational stakeholders should promote project based learning activities linked to STEM content to foster critical thinking and collaborative problem solving among students (Al Qoyyim & Nabila, 2025). Teacher education programs must integrate comprehensive STEM training modules to prepare future educators with pedagogical content knowledge specific to integrated STEM instruction (Bas, 2025). Policy initiatives should support the availability of open access, high quality STEM instructional resources that are culturally relevant and accessible for diverse learning environments (OpenSciEd, 2025). Schools and administrators need to establish partnerships with educational technology providers to expand access to adaptive and interactive learning tools that align with STEM objectives (Amran, 2025). Finally, ongoing evaluation and iterative refinement of STEM materials should be institutionalized to respond to feedback, emerging needs, and evidence from student performance outcomes (Al Qoyyim & Nabila, 2025).

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