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# Development of STEM-Based E-LKPD Using Deep Learning Principles to Improve Elementary School Students' Science Competence

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**Abstract:** Science education in elementary schools plays a vital role in developing scientific literacy, problem-solving skills, and reflective awareness. However, classroom practices are often teacher-centered and rely on printed worksheets that limit student engagement and competency development. This study aimed to design and evaluate a STEM-based Electronic Student Worksheet (E-LKPD) integrated with Deep Learning principles; joyful, meaningful, and mindful learning to enhance students' science competence in IPAS learning, which integrates natural and social sciences to support interdisciplinary understanding and real-world problem solving. The study employed a Research and Development (R&D) approach adapted from Borg and Gall, consisting of six stages: needs analysis, product design, expert validation, limited trial, revision, and large-scale implementation. Participants were 32 elementary students from a suburban public school with diverse academic and socioeconomic backgrounds. Data were collected using expert validation sheets, student response questionnaires, observation forms, and pretest–posttest assessments. Data analysis included descriptive statistics, Content Validity Index (CVI), paired-sample t-tests, and effect size calculations. Results indicated that the developed E-LKPD was feasible, with CVI scores in the valid to highly valid category. Students' science competence significantly improved, with mean scores increasing from 56.8 to 78.9 ($t(31) = 9.21$, $p < 0.001$, $d = 1.63$). Additionally, more than 75% of students reported positive learning experiences related to joyful, meaningful, and mindful learning. In conclusion, integrating STEM and Deep Learning principles into electronic worksheets is an effective strategy for strengthening elementary students' science competence and supporting 21$^{st}$ century learning.

***Abstrak:*** *Pendidikan sains di sekolah dasar memainkan peran penting dalam mengembangkan literasi sains, keterampilan pemecahan masalah, dan kesadaran reflektif. Namun, praktik di kelas seringkali berpusat pada guru dan bergantung pada lembar kerja cetak yang membatasi keterlibatan siswa dan pengembangan kompetensi. Studi ini bertujuan untuk merancang dan mengevaluasi Lembar Kerja Siswa Elektronik (E-LKPD) berbasis STEM yang terintegrasi dengan prinsip-prinsip Pembelajaran Mendalam; pembelajaran yang menyenangkan, bermakna, dan penuh perhatian untuk meningkatkan kompetensi sains siswa dalam pembelajaran IPAS, yang mengintegrasikan ilmu alam dan sosial untuk mendukung pemahaman interdisipliner dan pemecahan masalah dunia nyata. Studi ini* *menggunakan pendekatan Penelitian dan Pengembangan (R&D) yang diadaptasi dari Borg dan Gall, yang terdiri dari enam tahap: analisis kebutuhan, desain produk, validasi ahli, uji coba terbatas, revisi, dan implementasi skala besar. Partisipan adalah 32 siswa sekolah dasar dari sekolah negeri pinggiran kota dengan latar belakang akademik dan sosial ekonomi yang beragam. Data dikumpulkan menggunakan lembar validasi ahli, kuesioner respons siswa, formulir observasi, dan penilaian pra-uji dan pasca-uji. Analisis data meliputi statistik deskriptif, Indeks Validitas Konten (CVI), uji t sampel berpasangan, dan perhitungan ukuran efek. Hasil penelitian menunjukkan bahwa E-LKPD yang dikembangkan layak diterapkan, dengan skor CVI dalam kategori valid hingga sangat valid. Kompetensi sains siswa meningkat secara signifikan, dengan skor rata-rata meningkat dari 56,8 menjadi 78,9 (t (31) = 9,21, p < 0,001, d = 1,63). Selain itu, lebih dari 75% siswa melaporkan pengalaman belajar positif yang berkaitan dengan pembelajaran yang menyenangkan, bermakna, dan penuh perhatian. Kesimpulannya, mengintegrasikan prinsip-prinsip STEM dan Deep Learning ke dalam lembar kerja elektronik merupakan strategi yang efektif untuk memperkuat kompetensi sains siswa sekolah dasar dan mendukung pembelajaran abad ke-21.*

**Keywords:** Elementary School; E-worksheet (E-LKPD); IPAS Learning; STEM-based Learning

## INTRODUCTION

Understanding science from an early age is essential for helping elementary students develop the ability to reason logically, observe natural and social phenomena, and build positive scientific attitudes (Suradi et al., 2021; Aulls & Shore, 2023). In IPAS learning, science is integrated with social studies to provide a holistic understanding of natural-social interactions. Beyond basic concepts, science learning should foster curiosity, critical thinking, and problem-solving skills, forming the foundation for long-term scientific competence and interdisciplinary abilities.

However, evidence from classroom observations and large-scale assessments indicates that science learning in Indonesian elementary schools has not fully achieved these goals. Several studies and school-based observations reveal that science learning is still dominated by teacher-centred approaches, often relying on lectures and rote memorization (Komatsu et al., 2021; Prayogi et al., 2024).

Learning tools such as worksheets tend to be printed, static, and less interactive, which reduces students to passive recipients of information rather than active learners. This situation contributes to low levels of science competence. International assessments such as TIMSS and PISA consistently report that Indonesian students' science literacy levels remain below the global average, highlighting a fundamental challenge in the way science is taught at the primary level.

The demands of the 21st century further underscore the urgency of reform. Students are expected to master higher-order skills such as critical thinking, creativity, collaboration, and communication (4C), which are central to their ability to participate in modern knowledge-based societies. Science as a core subject should serve as an effective medium for cultivating these skills (Meyer & Norman, 2020; Wang et al., 2020). Yet, without the right pedagogical strategies and appropriate learning resources, these aspirations remain difficult to realize. One promising approach is STEM (Science, Technology, Engineering, and Mathematics) education. STEM emphasizes the integration of multiple disciplines to help students connect abstract concepts with real-world applications (Dare et al., 2021; Johnson & Czerniak, 2023). Prior studies have shown that STEM-based learning can improve creativity, higher-order thinking, and problem-solving skills, while also fostering students' interest in science and technology from an early age (Keleman et al., 2021). In the Indonesian context, STEM has been recognized as a pathway to enhance students' readiness for global challenges and technological advancement. Nonetheless, while STEM has gained traction, its integration at the elementary level remains uneven and often limited in scope.

Parallel to pedagogical advances, rapid digital transformation has made it possible to design more interactive and engaging learning tools (Voronin et al., 2020). Among these, Electronic Student Worksheets (E-LKPD) are particularly promising. Unlike static printed worksheets, E-LKPD can be enriched with multimedia features, interactivity, simulations, and automated feedback, thereby enabling both independent and collaborative learning (Rahmayani & Atmazaki, 2025). For teachers, E-LKPD offers flexibility in designing contextual, inquiry-based, and problem-solving tasks that align with STEM pedagogy. Despite the growing body of research on STEM-based E-LKPD, most studies still focus primarily on cognitive outcomes and do not sufficiently address the affective and reflective dimensions of learning (Kiswari et al., 2024). This has led to criticism that such tools risk reinforcing surface learning, namely short-term memorization, rather than fostering deep learning that is durable and transferable. Scholars argue that for science education to be transformative, it must engage learners not only cognitively but also emotionally and metacognitively.

In this context, Deep Learning is not defined in its technological sense of artificial intelligence, but rather as a pedagogical principle that emphasizes joyful, meaningful, and mindful learning (Sen, 2023; Jeet & Pant, 2023). Together, these principles create a holistic learning environment that supports both knowledge acquisition and the development of scientific attitudes.

The present study introduces a novel integration of STEM-based E-LKPD with Deep Learning principles. Unlike prior research that has treated STEM pedagogy and digital media design as separate concerns, this study unites them into a single instructional product. The uniqueness lies in the deliberate design of E-LKPD not only to deliver contextual, problem-based science content, but also to build a holistic learning experience that is engaging, relevant, and reflective. In doing so, the study responds to the dual challenge of raising students' science competence while also nurturing their curiosity, awareness, and critical engagement.

The significance of this research is threefold. Theoretically, it contributes to science education by offering a model that integrates STEM pedagogy with affective and metacognitive dimensions of learning. Practically, it provides teachers with an innovative digital tool that aligns with the principles of the *Merdeka* Curriculum, which emphasizes student-centred, contextual, and competency-based learning. Strategically, it supports national and global efforts to strengthen science literacy among Indonesian students, thereby preparing them to face future challenges in science and technology. In summary, this study aims to develop and validate a STEM-based E-LKPD with the integration of Deep Learning principles to improve elementary students' science competence. The results indicate that this approach is both feasible and effective, offering an important step forward in bridging cognitive, emotional, and reflective aspects of science education at the primary level.

## METHODS

This study used a Research and Development (R&D) design to produce and evaluate the feasibility and effectiveness of a STEM-based digital E-Assessment Worksheet (E-LKPD) integrated with Deep Learning principles in IPAS (natural and social science) learning. The development followed an adapted Borg and Gall model consisting of six stages: needs analysis, product design, expert validation, limited trial, revision, and wide-scale implementation (Borg & Gall, 2003; Plomp & Nieveen, 2013).

Participants included one elementary IPAS teacher and two student groups: a small-scale trial of 8–10 students and a wide-scale trial of 32 students. Needs analysis through classroom observation, teacher interviews, and student questionnaires identified limitations in printed worksheets and the need for an interactive digital medium to support active inquiry and interdisciplinary understanding in IPAS learning (Reinking, 2021).

The E LKPD was designed around IPAS competencies with multimedia, simulations, and problem-solving tasks. Deep Learning principles, namely joyful, meaningful, and mindful, were embedded through explicit and operational features. Joyful learning was implemented through interactive elements such as clickable images, drag and drop classification tasks, short gamified quizzes with instant feedback, and colorful animations that appear when student's complete milestones. Meaningful learning was supported through real world STEM problem scenarios (for example, analyzing local environmental changes), data interpretation tasks using simple digital simulations, and prompts that require students to connect activities with everyday experiences. Mindful or reflective learning was operationalized through reflection boxes at the end of each activity, where students summarized what they learned, evaluated their strategies, and responded to short metacognitive prompts such as "What part of today's investigation helped you understand the concept best and why?". These principles were embedded consistently across modules so that each page of the E LKPD included at least one joyful activity, one meaningful problem-solving link, and one mindful reflection prompt (Harlen, 2015). Moreover, Munir & Warmansyah (2023) highlight that students' activities in the elementary schools ideally involve physical, mental, social, emotional, and spiritual activities in the classroom.

Validation by content, media, and classroom experts assessed its alignment with STEM, IPAS learning, and Deep Learning principles. Usability was tested in a limited trial before refinement and implementation in the wide-scale trial (Atina et al., 2025). Data were collected using pretest–posttest achievement tests, student response questionnaires, and teacher observation sheets. Analysis included expert validation indices, descriptive student responses, qualitative observation summaries, and paired-sample t-tests with Cohen's d to determine effectiveness (Polit & Beck, 2006; Hattie & Donoghue, 2016).

The E-LKPD was considered successful when it achieved feasible or highly feasible validation scores, significant learning gains, and at least 75% positive student responses, ensuring both a validated product and evidence of its impact on enhancing science competence in IPAS learning (Hutcheson & Brown, 2024).

## RESULTS AND DISCUSSION

This section presents the research findings and their interpretation in relation to the research objectives and hypotheses stated in the introduction. The results are supported by data obtained from the implementation of the STEM-based E-LKPD integrated with Deep Learning principles in elementary science learning. The discussion is organized to provide both descriptive and analytical insights. First, the empirical results are presented as direct answers to the research problem, showing whether the stated hypotheses are confirmed. Second, these results are examined in light of relevant theories and previous studies to highlight their significance. In this way, this section not only reports the outcomes of the study but also interprets their educational implications within the broader context of science learning and curriculum development.

### *2.1. Expert Validation* Results

The STEM-based E-LKPD that was developed was validated by three experts with relevant qualifications and professional experience. The first expert was a science subject matter specialist holding a graduate degree in science education and with extensive experience in curriculum and concept development at the elementary level. The second expert was a learning media specialist with expertise in digital instructional design and more than five years of experience developing interactive learning materials. The third expert was an experienced fifth-grade science teacher who had practical knowledge of classroom implementation and the developmental characteristics of elementary students.

The validation results show that the E-LKPD falls within the “highly feasible” category, with an average validity score of 92%. The content aspect was assessed as highly relevant to basic science competencies and well-integrated with the STEM approach: the media aspect was judged to be attractive and interactive. Meanwhile, the linguistic aspects were considered communicative and appropriate for elementary school students.

**Table 1. Expert Validation Results for the STEM-Based E-LKPD Across Content, Media, and Language Aspects**

| Aspect | Expert 1 (Material) | Expert 2 (Media) | Expert 3 (Teacher) | Mean (%) | Category |
|---|---|---|---|---|---|
| Content Feasibility | 93% | - | - | 93 % | Very Eligible |
| Media Presentation | - | 91% | - | 91 % | Very Eligible |
| Language & Readability | - | - | 92% | 92 % | Very Eligible |
| **Overall Mean** | **92%** | | | **92 %** | **Very Eligible** |

The results in Table 1 indicate that the **content feasibility** aspect received a score of **93%** from the subject matter expert, meaning that the E-LKPD content aligns well with basic science competencies and integrates STEM concepts in an age-appropriate and contextual manner. The media presentation aspect was rated 91% by the digital learning media expert, showing that the interface design, layout, and interactive elements meet the criteria of effective digital instructional design. The language and readability aspect received a score of 92% from the experienced fifth-grade teacher, demonstrating that the wording is clear, communicative, and suitable for the cognitive development of elementary school students.

Overall, the average expert validity score reached 92%, categorized as very eligible. These results confirm that the developed STEM-based E-LKPD has met essential feasibility requirements in terms of content quality, media design, and linguistic appropriateness, making it suitable for progression to the classroom trial phase.

**2. Limited Trial Results**

A limited trial involving 10 students showed that most students found the E-LKPD easy to use, interesting, and helpful in understanding the material. Positive responses reached 85%, with minor improvements noted in menu navigation. Teacher observations also showed that students appeared enthusiastic and actively engaged in STEM-based activities, especially when asked to conduct simple experiments related to everyday life.

**Table 2. Summary of Student Responses During the Limited Trial of the STEM-Based E-LKPD (N = 10)**

| Indicator | Positive Response (%) | Category |
|---|---|---|
| Ease of Use | 88% | Very Good |
| Attractiveness | 85% | Very Good |
| Contribution to Understanding | 82% | Good |
| **Overall Mean** | **85%** | **Very Good** |

Table 2 shows that the limited trial produced a high level of positive student responses toward the STEM-based E-LKPD. Ease of use received the highest score at 88% (very good), followed by attractiveness at 85% (very good), and contribution to understanding at 82% (good). These results indicate that the E-LKPD is intuitive, visually engaging, and supportive of students’ comprehension of science concepts. The overall mean response of 85%

(very good) confirms its suitability for learning, requiring only minor refinements. Teacher observations further noted that students demonstrated enthusiasm, active participation, and strong motivation, particularly when conducting simple real-life experiments.

**3. Wide Trial Results**

A large-scale trial was conducted on 32 students to evaluate the effectiveness of the STEM-based E-LKPD integrated with Deep Learning. The science literacy test showed a significant increase from a pretest mean of 56.8 (SD = 8.4) to a post-test mean of 78.9 (SD = 7.6). The paired-sample t-test yielded t(31) = 9.21, p < 0.001, with a Cohen's d effect size of 1.63, indicating a large effect, as presented in Table 3.

**Table 3. Comparison of Pretest and Post-test Science Competence Scores After Using the STEM-Based E-LKPD (N = 32)**

| Test Type | Mean | SD | t(31) | p-value | Cohen's d | Category |
|---|---|---|---|---|---|---|
| Pretest | 56.8 | 8.4 | | | | |
| Post-test | 78.9 | 7.6 | 9.21 | <0.001 | 1.63 | Large Effect |

Table 3 shows that the STEM-based E-LKPD substantially improved students' science learning outcomes. The integration of joyful learning (through interactive digital experiments), meaningful learning (through real-life contextual tasks), and mindful learning (through reflective prompts) significantly enhanced students' understanding of science. Additionally, 84% of students found the learning process enjoyable, 82% meaningful, and 80% mindful, as summarized in Table 4.

**Table 4. Student Perceptions of Joyful, Meaningful, and Mindful Learning After Using the STEM-Based E-LKPD (N = 32)**

| Indicator | Positive Response (%) | Category |
|---|---|---|
| Joyful Learning | 84% | Very Good |
| Meaningful Learning | 82% | Very Good |
| Mindful Learning | 80% | Good |
| Overall Mean | 82% | Very Good |

Table 4 shows that joyful learning received the highest positive response at 84% (very good), indicating that students felt happy, motivated, and engaged through experiment-based activities and digital simulations. Meaningful learning scored 82% (very good), demonstrating that students could relate scientific concepts to real-life contexts. Mindful learning obtained a positive response of 80% (good), suggesting that most students reflected on their learning processes, though some required additional support. Overall, the average response of 82% (very good) confirms that the STEM-based E-LKPD integrating Deep Learning principles successfully provided a joyful, meaningful, and reflective learning experience that contributed to the development of students' science competencies.

These results further show that the STEM-based E-LKPD significantly improved elementary students' science competence, aligning with STEM education theory which emphasizes the integration of science, technology, engineering, and mathematics in authentic contexts to foster problem-solving, critical thinking, and creativity (Bybee, 2013). When combined with the deep learning framework, which stresses meaningful, connected, and long-lasting learning (Seo et al., 2022; Bagherzadeh et al., 2023), the E-LKPD functions not only as a digital learning tool but also as a medium for transformative science learning.

Previous research supports these findings, showing that E-LKPDs and other digital worksheets can enhance student engagement and independence, particularly when designed to be interactive and contextual (Yanah, 2024). The integration of STEM into digital learning environments has been found to improve students' conceptual understanding, scientific literacy, and problem-solving abilities (Kennedy & Sundberg, 2020; Govender, 2025), while the application of deep learning principles, such as connecting prior knowledge to new content, encouraging collaborative inquiry, and fostering reflective thinking, enhances higher-order thinking and knowledge retention (Biggs et al., 2022; Fullan et al., 2018).

The improvement in science competence aligns with Vygotsky's sociocultural theory, which emphasizes interaction and scaffolding (Daramola et al., 2024), as well as Piaget's constructivism, which highlights active engagement and meaning-making Piaget (Piaget, 1972; Zajda, 2021). Moreover, the findings resonate with Self-Determination Theory, which posits that student motivation and persistence increase when autonomy, competence, and relatedness are nurtured through joyful, meaningful, and mindful learning experiences (Deci & Ryan, 2000). These insights underscore the importance of designing educational environments that support students' emotional and spiritual well-being alongside academic engagement. In this regard, A'ini et al. (2025) highlight the need for Islamic educational institutions to integrate spiritual approaches into curricula, guidance services, and mentoring programs to foster holistic, supportive learning environments. Collectively, these studies indicate that scientific and religious learning are strengthened when students experience meaningful interactions, intrinsic motivation, and contextualized learning opportunities (Suhada & Surawan, 2025).

Digital learning tools, whether STEM-based E-LKPDs for science or digital PAI resources, can enhance education quality by integrating natural and social sciences, fostering scientific competence, critical thinking, and interdisciplinary understanding. Designed with deep learning principles, these tools enable joyful exploration, meaningful application, and mindful reflection, while digital PAI learning similarly strengthens students' competencies in Islamic Education (Abu et al., 2025). Additionally, the use of platforms such as Miro positively supports collaborative learning by facilitating idea expression, shared understanding, and structured visual solutions (Putri & Surawan, 2025).

The integration of deep learning principles contributed substantially to the observed outcomes through joyful, meaningful, and mindful learning. These interconnected dimensions foster engagement, intrinsic motivation, and long-term retention of scientific knowledge. Joyful learning, implemented through ice-breaking activities, mind-mapping discussions, creative presentations, and interactive quizzes, has been shown to create lively and participatory classrooms (Lutfi et al., 2025). Positive emotions enhance motivation, creativity, and persistence in learning (Ramzan et al., 2023), while embedding interactive experiments and digital games in the E-LKPD promotes curiosity and enjoyment, consistent with Csikszentmihalyi flow theory (1990). Prior research confirms that joyful, game-based digital learning improves engagement and conceptual mastery in STEM subjects (Wang, 2020; Behnamnia, 2021).

Meaningful learning occurs when students connect new concepts to prior knowledge and real-life contexts (Ausubel et al., 1978; Sexton, 2025). In this study, the E-LKPD enabled students to relate science topics such as energy, ecosystems, or materials to their everyday experiences, making abstract concepts more tangible. Contextualized STEM activities promote critical thinking, problem-solving, and science literacy (Hebebci & Usta, 2022; Pertiwi et al., 2024).

Mindful learning, supported by reflection, self-assessment, and metacognition, encourages students to take responsibility for their learning processes (Langer, 2016; Moritz & Lysaker, 2018). Structured reflection questions and self-assessment tasks in the E-LKPD helped students evaluate their progress and refine strategies, while mindfulness practices improve attention, reduce anxiety, and support deeper conceptual understanding (Schwind et al., 2017). Together, joyful, meaningful, and mindful learning create a holistic educational experience integrating emotion, cognition, and reflection. The use of contextual learning media, such as stamping in fine arts, enhances motivation, participation, and learning outcomes, emphasizing creative, innovative, and enjoyable learning connected to students' environments (Pangestu & Sakre, 2025). In science education, embedding such dimensions ensures competency development while cultivating motivation, relevance, and self-regulation, fostering sustainable learning beyond the classroom.

The findings are consistent with prior studies demonstrating that STEM-based instruction strengthens higher-order thinking, problem-solving, and scientific literacy (Beers, 2011; Tan et al., 2023). Integrating science, technology, engineering, and mathematics provides opportunities for inquiry-based learning, collaboration, and authentic application of knowledge (Bybee, 2013). Digital tools such as E-LKPD increase engagement and learning independence when tasks are interactive and contextualized (Rahmayani & Atmazaki, 2025; Susanti et al., 2025; Gardner et al., 2019; Vieira et al., 2025)

This study is distinctive in explicitly combining STEM pedagogy with deep learning principles in digital worksheets. While previous research often focused on cognitive outcomes, this study integrates affective (joyful), cognitive (meaningful), and metacognitive (mindful) dimensions, reflecting Fullan & Langworthy (2014), view that deep learning develops knowledge, skills, attitudes, and self-awareness. Game-based STEM studies typically emphasize enjoyment (El Mawas et al., 2022), whereas mindfulness interventions focus on reflection and self-regulation (Bockmann & Yu, 2023). Motivation plays a crucial role in achievement, and teachers are expected to cultivate it through strategies aligned with students' interests and capacities (Malisi et al., 2023).

This study demonstrates that integrating joyful, meaningful, and mindful learning within a STEM-based E-LKPD enhances student engagement, deepens understanding, and strengthens learner autonomy, providing a model for designing digital STEM resources that promote both academic achievement and personal growth. In the context of IPAS learning, which integrates natural and social sciences in elementary education, this approach not only develops scientific competence but also fosters interdisciplinary understanding, critical thinking, and reflective skills.

The findings highlight that STEM-based E-LKPD integrated with deep learning principles supports emotional engagement, cognitive understanding, and reflective awareness, aligning with constructivist theories (Piaget, 1972; Vygotsky, 1978), and offering a comprehensive framework for meaningful, student-centered IPAS learning. Moreover, the results support Self-Determination Theory, indicating that students' motivation and persistence increase when autonomy, competence, and relatedness are nurtured through joyful, meaningful, and mindful experiences (Deci & Ryan, 2000).

Practically, the STEM-based E-LKPD provides teachers with an innovative digital tool aligned with the *Merdeka* Curriculum, enabling active, contextual, and student-centered IPAS lessons (Lestari et al., 2021; Alifah & Abidin, 2025). By incorporating problem-based tasks, real-world applications, and reflective activities, it promotes engaging and effective classroom practices, while adaptive strategies such as gamification and project-based learning support both academic achievement and character development (Ria & Surawan, 2025). AI integration in religious education also requires contextual adaptation, teacher training, and ethical guidelines to maintain learning quality and respect cultural values (Djazilan et al., 2024; Rustanta, 2025; Papakostas, 2025). Strategically, these findings enhance students' science literacy, critical thinking, and problem-solving skills, preparing them to be adaptive and responsible global citizens (Chu et al., 2021; Siregar et al., 2023).

Integrating STEM-based E-LKPDs in IPAS learning strengthens interdisciplinary understanding, creativity, reflective thinking, and digital literacy, while guided digital tools, such as Miro and social media, support collaboration and self-expression (Putri & Surawan, 2025; Norhidayah et al., 2026).

Embedding deep learning principles through joyful, meaningful, and mindful activities, supported by interactive experiments and digital simulations, increases engagement, motivation, and conceptual mastery (Seo et al., 2022; Bagherzadeh et al., 2023; Lutfi et al., 2025; Ramzan et al., 2023; Vieira et al., 2025). Meaningful learning connects new concepts to prior knowledge and real-life contexts (Ausubel et al., 1978; Sexton, 2025; Hebebci & Usta, 2022), while mindful learning fosters reflection, self-assessment, and metacognition, enhancing attention, understanding, and self-regulation (Langer, 2016; Moritz & Lysaker, 2018; Schwind et al., 2017). These strategies create a holistic learning experience that makes science education relevant, motivating, and sustainable.

These results are consistent with previous studies showing that STEM-based instruction and digital worksheets improve higher-order thinking, problem-solving, and science literacy (Beers, 2011; Tan et al., 2023; Bybee, 2013; Rahmayani & Atmazaju, 2025; Susanti et al., 2025). Unlike prior research that often focuses on either cognitive or affective outcomes, this study integrates joyful, meaningful, and mindful learning within STEM pedagogy, simultaneously supporting knowledge, skills, attitudes, and self-awareness (Fullan & Langworthy, 2014). By combining these elements, the STEM-based E-LKPD amplifies engagement, conceptual understanding, and learner autonomy, offering a robust model for digital STEM resource design that nurtures both academic and personal growth.

Future research should explore scalability across grade levels and school contexts, longitudinal effects on students' scientific attitudes, creativity, collaboration, and problem-solving, integration with emerging technologies such as augmented reality and adaptive learning, and teacher professional development to ensure effective implementation. Pursuing these directions can further establish the role of STEM-based, deep learning–oriented digital worksheets in transforming elementary IPAS education.

## CONCLUSION

This study successfully developed and validated a STEM-based Electronic Student Worksheet (E-LKPD) integrated with Deep Learning principles to enhance elementary students' science competence. The findings demonstrate that merging STEM approaches with joyful, meaningful, and mindful learning creates a holistic digital resource that not only strengthens cognitive outcomes but also fosters curiosity, reflection, and active participation.

Theoretically, the research enriches the field of science education by showing how affective and reflective dimensions can be embedded within STEM-based digital materials. Practically, the E-LKPD provides teachers with an adaptable tool aligned with the Merdeka Curriculum and responsive to the demands of 21st-century scientific literacy.

Further studies should investigate the application of this model across different grade levels, school contexts, and subject areas to test its generalizability. Longitudinal research is recommended to examine whether improvements in science competence are sustained and whether they promote higher-order skills such as creativity, collaboration, and problem-solving. Future development may also integrate emerging technologies, including augmented reality and adaptive systems, to advance personalization and interactivity in elementary science learning.

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