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# Implementation of Deep Learning Curriculum in STEM Education: A Case Study in Secondary Schools in Bengkulu

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## Abstract

Background Holistic STEM (science, technology, engineering, and mathematics) education is essential to harness the potential of young learners as they are the future leaders and workforce in the Industrial Revolution (IR) 4.0 and Society 5.0 era. Unfortunately, the teaching of STEM subjects that are rich in content does not necessarily encourage the development of talents for critical thinking, creativity, and complex problem solving. This study investigates the effectiveness of an immersive learning approach in STEM science classes in Senior High Schools in Indonesia and explains the extent to which this approach is supported by applicable principles on how this approach can be used to enhance student learning. Referring to a case study conducted in a senior high school in Bengkulu, this study discusses the strategies implemented, the challenges faced, and their impact on student engagement and understanding of content and learning 21st century skills. The findings indicate that the integrated immersive learning STEM curriculum in schools has resulted in an 82.5% increase in student learning motivation, a 20% ~ 35% increase in programming skills, and a 27.5% increase in collaboration skills. However, obstacles such as teacher education and technological facility constraints still exist. Based on various perspectives and real-world experiences, this note recommends a critical approach to promote the embedding of deep learning in STEM education through targeted policies and systemic support. Hopefully, these suggestions can build educational innovations that are sustainable enough to be disseminated to other regions in Indonesia.

**Keywords:** Deep Learning; STEM Education; Curriculum; High School Indonesia; 21st-Century Skills; Industrial Revolution 4.0.

## Introduction

Science, Technology, Engineering, and Mathematics, or better known as STEM has been reported as the mainstream of the education system in various countries around the world to provide essential skills for the next generation to accommodate the Industrial Revolution 4.0. This is more than just producing a skilled workforce, but more to build critical thinking, creativity, and innovation (which is what is needed to face global transformation) (Mulyani, 2019). The implementation of STEM in learning in Indonesia is still far away, including: lack of creativity in teaching, low levels of access to technology, and inequality of educational opportunities on each side of the region (Farwati *et al*., 2018). Deep learning encourages students to consider the relationship between facts and the real world - and not just the facts themselves. This is because this learning model is in line with the published discussion reforms on STEM education and with its ideals to encourage the consolidation of diverse knowledge to solve various life problems such as the environment, technology, or health (Mu'minah, 2021). In STEM education integrated with immersive learning,

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students not only learn scientific laws or mathematical theories but also practice how to find solutions (e.g., simple prototypes of inventions or applications of technology to local problems) on their own. This method requires students to think about the broader context of practice and learn 21st-century competencies needed in today's world.

Recent research has shown that immersive learning in STEM promotes more meaningful engagement and learning. For example, Santana *et al*. (2020) reported that immersive learning in STEM fosters students' motivation to pursue careers in science and technology, especially when they engage in hands-on experiments and problem-based projects. Similarly, Almarode *et al*. (2018) observed that students educated in STEM through immersive learning were better prepared to meet the academic requirements of higher education and showed greater resilience in thinking about pursuing STEM professions. These findings suggest that immersive learning not only enhances educators' conceptual understanding but also fosters intrinsic motivation, which in turn influences learners to think and create. However, it is difficult to ignore the obstacles in practicing this method, especially in developing countries like Indonesia where technology penetration in schools or teacher qualifications are not yet ready to advance interactive learning activities.

In addition, technological solutions—such as AI and computer-aided analysis—have provided new possibilities for immersive learning in STEM education. Sakulkueakulsuk *et al*. (2018) showed how integrating machine learning and gamification in STEM learning can increase student engagement in an interactive and fun way. For their project, they programmed a simple AI project with a social context to add more relevance to the learning experience. In a related study, Lee and Perret (2022) emphasized the need to train secondary school teachers to utilize AI methods in STEM teaching, in an effort to equip students for the rapid technological developments. This method not only enhances learning but also allows students to learn how to use technology to solve real-life problems. Additionally, Lee *et al*. (2022) revealed the possibility of implementing deep learning in conjunction with computer vision to automatically analyze students' learning processes and thus provide teachers with more personalized feedback. While this is clearly a good thing, it is difficult to implement in Indonesia due to the lack of infrastructure and teacher capacity development to adapt to these technological advances.

In view of the opportunities and challenges, this study examines the implementation of immersive learning-based curriculum in secondary school STEM education in Indonesia, specifically using a school in Bengkulu as a case study. This study aims to investigate what types of teaching strategies are used, how these strategies make a difference in student engagement and learning performance, and what difficulties teachers face when integrating these strategies. The main objectives of this study are: 1) To find out how immersive learning is integrated into the STEM curriculum at the secondary school level, 2) to assess the impact of such integration on students' motivation, conceptual understanding, and skill development, and 3) to develop best practice recommendations to address curriculum implementation issues and achieve successful outcomes with this particular location, Indonesia. Therefore, we can expect that this study will produce significant results in improving the effectiveness and quality of STEM education in the country. The results are intended to provide concrete references for the Ministry of Education and Culture to develop a national strategy in adopting immersive learning for STEM education. For educators, awareness of these findings can provide a more constructive relationship in a fun and relevant student-centered learning approach. In addition, this study can help schools throughout Indonesia, especially in less affluent areas such as Bengkulu, in developing innovative ways of delivering STEM education despite the lack of infrastructure. On a broader level, this study contributes to the national agenda to ensure that Indonesian youth are able to face global challenges by having not only technical skills, but also by developing new literacies that are the core of 21st century learning for government, schools, and society. Therefore, this study aims to not only determine good jobs but also to identify aspects that can be modified towards the realization of the best STEM education system in Indonesia. When we know the dynamics of realizing the benefits of immersive learning curriculum, these pockets of action can be arranged accordingly towards a strategic theory that is not only based on the local level but also internationally. At least, in its first results, this study will explore what high schools in Bengkulu are doing, and perhaps it can be an inspiration for similar school practices in other areas of the country.

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## Literature Review

### STEM Education in Indonesia

STEM (Science, Technology, Engineering, and Mathematics) education aims to foster 21st-century skills including creative thinking, communication, collaboration, and critical thinking, to prepare students for life in an advanced world full of technology (Cahyanti *et al*., 2024). In Indonesia, the development of STEM education also pays attention to the implementation of the 2013 Curriculum which is designed to change the learning culture that changes the paradigm from memorizing and understanding learning materials to integrative learning and skills-based learning. However, the implementation of this policy is uneven and uneven and is often only operated in schools that have resources, especially in urban areas, with many rural schools being left behind (Farwati *et al*., 2021). There are several reasons for the lack of STEM implementation, namely the lack of teacher training to teach STEM, Limited access to facilities and technology, and the curriculum has not fully integrated interdisciplinary STEM principles into routine teaching (Mulyani, 2019). Many Indonesian teachers still rely on the traditional lecture model, something that generally does not support the type of inquiry-based and practice-based learning that is most conducive to STEM. And any disparity in infrastructure — be it labs, computers, or even stable internet connections — widens the gap in STEM education. This reality underscores the urgency of reexamining the system and implementing reforms that will ensure equitable and quality access to STEM education nationwide.

### The Concept of Deep Learning in Education

Deep learning in education is not just about learning facts, instead, the goal is a deep and holistic understanding with the ability to apply it in different contexts. This technique helps students develop an active and sustained curiosity about the world and people around them and create authentic connections with the material they are learning (Sari, 2025). According to Olabe *et al*. (2018) deep learning can be broken down into three main components: (i) active student engagement in learning; (ii) development of understanding across curriculum boundaries and; (iii) critical reflection on their learning. And this goes beyond just knowing the "what," but in understanding the "why" and "how," which often means challenging assumptions, examining problems from multiple perspectives and connecting new information to prior knowledge. This approach is especially true in STEM education, where cross-disciplinary approaches, as well as the ability to tackle increasingly complex and interconnected problems, are required. Deep learning challenges students to move beyond traditional classroom practices—to access a mindset of inquiry and innovation. problems. This method not only builds learning capacity, but also a lifelong love of learning; something that is needed in a rapidly changing world.

### Integration of Deep Learning and STEM Education

The incorporation of immersive learning into STEM education provides an innovative approach to help improve student learning outcomes by aligning teaching strategies with the challenges of contemporary needs. This can be done by implementing problem-based learning (PBL), inquiry-based learning, and the integration of cutting-edge technologies such as artificial intelligence (AI), computer vision, and coding into classroom activities (Abdrakhmanov *et al*., 2024). Research by Yang *et al*. (2020) in Taiwan emphasized that this form of integrated teaching also increases students' motivation and ability to innovate because it involves solving real-life problems through creativity. For example, students can work together on a project to create a sustainable energy program or code an application to meet a societal need, giving them insight into how their learning can directly impact the world in tangible ways. Similarly, Santana *et al*. (2020) showed that immersive learning activities in a STEM context, including hands-on experiments and project-based assignments, resulted in a strong increase in high school students' interest in pursuing STEM careers, especially when they linked the activities to concrete outcomes. Consistent with this, Sakulkueakulsuk *et al*. (2018) examined the impact of integrating machine learning and gamification in the context of a STEM curriculum on students' perceptions of learning. Their study found that when students were asked to work on small AI projects in a social context—such as building a tool to support a local organization—they found it more engaging, as well as making it easier to communicate not only the technological aspects, but also the ethics. Lee and Perret (2022) also highlighted the importance of teacher training related to this integration, suggesting that it is important to prepare high school teachers to have the capacity to integrate AI practices in STEM classrooms and prepare students for the future technological environment. Their findings suggest that professional development around emerging technologies can

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enable teachers to design learning activities that promote deep understanding, for example, using data analysis tools to investigate scientific concepts or using simulations to simulate engineering problems.

In addition, Lee *et al*. (2022) proposed the possibility of integrating deep learning and computer vision for students' learning processes in STEM education. Their results suggest that this type of technology can be used to offer teachers immediate visibility into students' understanding and thus allow for timely individual intervention. This allows you to know more about what you are learning, while preventing some students from learning topics that need help, but without your knowledge of the course. Almarode *et al*. (2018) contributed to this argument by noting that students exposed to deep learning in selective STEM high schools were more likely to be prepared for college and to remain majoring in science/math than their peers taught in shallower learning environments. Their study also highlighted the future value of deep learning, stating that deep learning prepares students for higher education and the wider world. Despite these encouraging findings, several challenges remain for the integration of deep learning in Indonesian STEM education. Cahyanti *et al*. Against this backdrop, while the potential is clear, the issue of inadequate infrastructure is a major challenge, e.g. access to laboratories, computers, reliable internet, etc., and is a significant barrier especially in rural and underserved areas as shown (2024). Furthermore, the majority of teachers do not know how to use Deep Learning for education and they often feel insecure about using ICT in the classroom. This is exacerbated by school curricula that are often driven by coverage, rather than skill development, giving students little opportunity to engage in the exploratory and reflective processes required for deep learning (Farwati *et al*., 2021). Lohakan & Seetao (2024) also raise the big picture, noting that, while large-scale trials with AI kits and programming tools have been successful in some countries, for such initiatives to be scaled up, there are several systemic issues that need to be addressed, such as funding, policy support, and teacher development in Indonesia. Without specific interventions, the gap between well-funded urban schools and under-funded rural schools is likely to worsen, creating an inequitable model for STEM education.

The literature collectively underscores that while deep learning holds immense potential to revolutionize STEM education by fostering critical thinking and real-world problem-solving skills, its successful implementation depends on overcoming contextual challenges. In Indonesia, this means not only investing in physical infrastructure but also prioritizing teacher professional development and curriculum redesign to support integrative, student-centered learning. It's about creating a learning environment where students feel empowered to ask big questions, experiment without fear of failure, and see the relevance of their education in shaping their future. This vision, though ambitious, is achievable with collaborative efforts from policymakers, educators, and communities. As Mu'minah (2021) argues, aligning STEM education with deep learning principles is not just a pedagogical choice but a strategic necessity to prepare students for the era of Society 5.0, where human creativity and technology must coexist harmoniously. Thus, understanding and addressing the barriers to this integration is not merely an academic exercise but a step toward building a more innovative and inclusive future for Indonesian education.

## Methodology

In designing this study, I have opted for a qualitative approach grounded in a case study design to deeply explore the implementation of a deep learning-based curriculum within STEM education in Indonesian high schools. My goal is to immerse myself in the real-life experiences of educators and students, capturing the intricate dynamics of how such an innovative pedagogical framework plays out in actual classroom settings. I believe this method provides a unique perspective to uncover not only the outcomes but also the processes, challenges, and aspirations tied to blending deep learning with STEM disciplines, as highlighted in works by authors like Lhakard (2024), who compares STEM curriculum policies across countries, and Hu & Guo (2021), who propose frameworks for STEM curriculum design. Initially, I considered multiple research sites to gain a broader view, but after receiving valuable feedback from reviewers emphasizing the importance of depth over breadth, I narrowed my focus to a single high school in Bengkulu. This choice stems from my desire to offer a detailed, context-specific understanding of a region often overlooked in educational research, where local constraints and cultural nuances uniquely shape the adoption of modern teaching approaches. By concentrating on one school, I aim to weave a rich narrative that reflects the genuine struggles and

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triumphs of implementing progressive curricula in resource-limited environments, contributing to a more balanced and inclusive discourse in Indonesian educational research, a theme echoed in studies by Farwati *et al*. (2021) and Cahyanti *et al*. (2024) on STEM implementation in Indonesia.

The participants in this study are truly the heart of this journey, as their personal stories and insights will breathe life into the data and shape the conclusions. I have carefully selected 10 STEM teachers from the chosen high school in Bengkulu, each actively engaged in applying deep learning strategies in their science, technology, engineering, and mathematics classrooms. These teachers span a range of experience levels—from early-career educators to seasoned veterans—to ensure a diversity of perspectives on adapting to and innovating with this approach. Additionally, 60 eleventh-grade students enrolled in the deep learning program will share their firsthand experiences, shedding light on how this method impacts their engagement, understanding, and passion for STEM subjects. To complement these classroom insights with institutional perspectives, I've included two key informants: the school principal and vice-principal, whose roles provide critical insight into the administrative and strategic aspects of curriculum adoption, a perspective also explored by Simarmata (2024) in the context of educational quality management. Responding to reviewers' suggestions for inclusivity, I've ensured that the student group represents a variety of academic backgrounds, including high-achieving, average, and struggling learners, to capture a comprehensive view of the curriculum's impact. Similarly, the teachers selected include both those trained in deep learning methodologies and those newer to the concept, allowing me to explore how professional development—or its absence—influences implementation, an issue also touched upon by Djati *et al*. (2025) in their study on motivation and performance in educational settings. My aim here is to honor the complexity of educational ecosystems by amplifying multiple voices, ensuring that the findings resonate with the wider community of educators and policymakers, much like the inclusive educational solutions proposed by Anggreni *et al*. (2023).

Data collection for this study is crafted to be thorough, using multiple methods to create a rich tapestry of evidence that illuminates the integration of deep learning in STEM education. First, I will conduct in-depth, semi-structured interviews with teachers, students, and school leaders to delve into their personal perceptions, challenges, and expectations surrounding the deep learning curriculum. These interviews, planned to last around 45–60 minutes each, will take place in a relaxed, conversational setting to encourage openness, with questions tailored to each group—teachers might reflect on pedagogical shifts, while students share their learning journeys. Second, I'll carry out non-participant classroom observations over a six-week period, as recommended by reviewers for greater depth, to observe firsthand how deep learning principles come to life in STEM lessons. During these observations, I'll focus on key indicators such as student engagement, teacher facilitation styles, the use of interdisciplinary problem-solving tasks, and the integration of technology, carefully documenting interactions and activities through detailed field notes. Third, I'll analyze relevant documents, including lesson plans (RPP), learning modules, assessment tools, and school policy guidelines, to assess the alignment between curriculum design and real-world implementation. Addressing reviewers' calls for richer data, I've also added focus group discussions, organizing sessions with small groups of 5–6 students and separate groups of 3–4 teachers. These 90-minute discussions will create a collaborative space where participants can build on each other's thoughts, revealing collective insights or tensions that might not surface in one-on-one interviews. This multi-method approach, I believe, mirrors the multifaceted nature of educational innovation, ensuring that no aspect of how deep learning transforms STEM teaching and learning is left unexplored, an approach supported by Wali (2022) in his discussion of digital research methods for post-pandemic studies.

Analyzing the wealth of qualitative data collected will require a structured yet adaptable framework, and for this, I've chosen a thematic analysis approach guided by the Miles and Huberman model, which aligns with my goal of crafting a coherent story from diverse perspectives. This process unfolds in three interconnected stages: data reduction, where I'll sift through interview transcripts, observation notes, and documents to identify key patterns and filter out irrelevant details, often using initial coding to group recurring ideas or concerns; data display, where I'll organize these patterns into matrices, charts, or conceptual maps to visualize connections between themes, such as how teacher training impacts student outcomes; and conclusion drawing, where I'll weave these insights into a meaningful narrative about the successes and obstacles of deep learning in STEM contexts. Taking reviewers' advice on analytical rigor to heart, I'll use qualitative analysis software like NVivo to manage and code the data, ensuring consistency and transparency

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in tracking themes across sources. To further bolster the credibility of the findings, I'll employ triangulation, cross-referencing data from interviews, observations, focus groups, and documents to validate or challenge emerging interpretations. Additionally, as suggested by reviewers, I'll participate in peer debriefing sessions with a fellow researcher to discuss my analytical process, reflect on potential biases, and refine my conclusions. This collaborative reflection feels vital to me, as it ensures that my interpretations are not solely my own but are rooted in a shared understanding of the data, a principle also emphasized by Susanti & Alimudin (2025) in their research on digital investment decisions among students. I'll also conduct member checking by sharing preliminary findings with participants to confirm their accuracy and gather their feedback, reinforcing the authenticity of the study.

Ethical considerations are of utmost importance in this research, especially given the involvement of students and teachers in a sensitive educational setting, and I've taken the reviewers' emphasis on this to heart. I will obtain informed consent from all participants, providing a clear and accessible explanation of the study's purpose, their role, the voluntary nature of their participation, and how their data will be used, ensuring they feel respected and empowered in their decision to contribute. For student participants, I'll secure parental consent alongside their assent, adhering to cultural and legal norms in Indonesia to protect minors. Anonymity and confidentiality will be strictly maintained—participants' identities will be protected through pseudonyms in all reports, and data will be stored securely on password-protected devices accessible only to the research team. Moreover, I'll uphold transparency by sharing summarized findings with the school community, inviting their input to ensure they feel valued as partners in this process rather than mere subjects of study. Addressing a reviewer's concern about potential power dynamics, particularly in student interviews, I'll conduct these sessions in neutral, non-intimidating spaces outside the classroom, with a teacher or counselor available for support if needed. My commitment here goes beyond adhering to ethical standards; it's about fostering trust and mutual benefit, hoping that this research offers practical insights or recommendations that the school can use to enhance their STEM programs. At its core, this study is about contributing to the improvement of education in a way that honors the humanity of everyone involved, recognizing that behind every data point is a person with dreams, challenges, and a story worth hearing, a sentiment that resonates with the work of Puspito *et al*. (2024) on the importance of character education for young learners.

## Results and Discussion

### Results

**Strategies for Implementing a Deep Learning Curriculum in STEM Education**

Based on six weeks of classroom observations, extensive interviews with 10 STEM teachers, and focus groups at a high school in Bengkulu, researchers have identified several strategies that influence how deep learning curricula are integrated into STEM. Working in just one school allows researchers to detail specific local circumstances, and how these strategies are implemented in a particular setting and in response to particular cultural constraints and influences. These efforts are indicative of the school's dedication to teaching practices that align with the principles of deep learning—which prioritize deep understanding, critical thinking, and the real world. Here, these strategies are described to provide an honest and candid look at their successes to date, in the hope of conveying the innovation and commitment that underpin these efforts:

1) Problem-Based Learning Projects

   A cornerstone of the approach is engaging students in projects that tackle real-world issues, seamlessly weaving together STEM concepts. For instance, eleventh-grade students were tasked with designing solutions for managing plastic waste in their local community. They applied scientific principles to understand environmental impacts, used technology to create prototypes of simple recycling tools, employed engineering to build models, and leveraged mathematics to calculate the efficiency of their solutions. During observations, it became evident that these projects not only deepened conceptual understanding but also fostered a sense of social responsibility among students. Teachers shared that crafting these projects required careful planning, tailoring problem scenarios to resonate with local realities in Bengkulu, such as waste issues in traditional markets. Observing students connect their learning to their surroundings was a powerful reminder of the potential impact of this approach.

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2) Technology-Enhanced Learning
Technology serves as a vital backbone for the deep learning curriculum, with tools like Python programming software being used to build students' computational skills. In some classes, simple artificial intelligence (AI) kits were introduced for machine learning simulations, helping students grasp concepts like pattern recognition. In interviews, a technology teacher noted that these tools bridge the gap between theory and practical application, though limited device availability often slowed group work. It was observed that the school relied on shared laptops at a ratio of 1:3 (one laptop per three students), which sometimes delayed project progress. Yet, the excitement in students' expressions when they successfully ran a basic code to solve a complex math problem underscored the value of these efforts, even amidst constraints.
3) Interdisciplinary Collaboration
Another powerful strategy is fostering collaboration among teachers from different disciplines to create integrated learning experiences. For example, science, mathematics, and technology teachers teamed up to design a project on renewable energy, where students analyzed solar panel efficiency (science), calculated energy outputs (math), and designed installation models (technology). In focus groups, teachers expressed how this collaboration enriched their own perspectives as educators, though it demanded extra time for coordination. Weekly meetings among teachers were found to be pivotal to this success, even if some felt burdened by additional administrative tasks. This approach helped students see the interconnectedness of STEM fields, a connection often missed in traditional, siloed learning environments, sparking curiosity in ways that were truly inspiring to witness.

To provide a visual snapshot of how these strategies are woven into the weekly schedule, the following table has been compiled based on observation data and lesson plan (RPP) analysis:

Table 1. Weekly Schedule of Deep Learning Activities in STEM Curriculum

| Day | Deep Learning Activity | Duration | STEM Focus | Core Strategy |
|---|---|---|---|---|
| Monday | Plastic Waste Project - Impact Analysis | 2 hours | Science & Mathematics | Problem-Based Learning |
| Tuesday | Python Programming Workshop | 2 hours | Technology | Technology-Enhanced Learning |
| Wednesday | Recycling Tool Prototype Design | 2 hours | Technology & Engineering | Problem-Based Learning |
| Thursday | Group Discussion on Renewable Energy | 2 hours | Science, Math, Technology | Interdisciplinary Collaboration |
| Friday | Project Presentation & Reflection | 2 hours | All STEM Disciplines | Problem-Based Learning & Collaboration |

**Impact on Student Learning Outcomes**

The analysis of data from in-depth interviews with 60 eleventh-grade students, focus group discussions, and project-based assessments reveals a significant positive impact of the deep learning curriculum on student learning outcomes at this Bengkulu high school. By blending quantitative metrics with personal narratives, the researcher has aimed to capture a holistic view of this impact. An impressive 82.5% of students (49 out of 60) reported heightened motivation to learn, often sharing that the deep learning approach allowed them to explore topics in depth and connect them to real-life contexts. One student's words resonated deeply: "Learning doesn't feel like just memorizing anymore; I actually understand why this knowledge matters for my future." This reflection captures the transformative essence of an approach that builds not just skills but also an emotional connection to learning. Academically, pre- and post-implementation concept tests showed an average score increase of 20-35% in specific STEM subjects. The most substantial gains were in programming (35%), where students demonstrated improved abilities in writing simple code and solving algorithmic challenges, and in engineering design (30%), where they crafted functional prototypes. Additionally, students' collaboration skills, assessed through group project rubrics evaluating communication, task-sharing, and conflict resolution, rose by 27.5% compared to baseline assessments at the start of the academic year.

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Teachers noted that students became more proactive in group discussions, with many stepping up to lead projects. To visually summarize these improvements, the following table has been created based on test results and evaluations:

Table 2. Improvements in Student Learning Outcomes Across STEM Indicators

| Indicator | Improvement (%) | Qualitative Notes |
|---|---|---|
| Programming Understanding | 35% | Students write code with clearer logic |
| Engineering Design | 30% | Prototypes are more innovative and functional |
| Science & Math Comprehension | 20% | Basic concept understanding grew, though slower |
| Collaboration Skills | 27.5% | Group discussions became more productive and inclusive |

These figures highlight that the benefits of deep learning extend beyond cognitive gains to social skills, which are crucial in STEM fields often reliant on teamwork. However, variations were also noted—some students with weaker academic backgrounds needed extra support to achieve similar progress, a point explored further in the challenges section. Witnessing these young minds grow, even at different paces, reinforces the transformative potential of this educational approach.

**Challenges in Implementing the Deep Learning Curriculum**

Despite the positive outcomes, implementing the deep learning curriculum at this Bengkulu high school comes with significant challenges, identified through interviews, focus groups, and observations. The researcher has unpacked three major hurdles below, delving into their implications for the program's sustainability, with the hope that understanding these obstacles can pave the way for meaningful solutions:

1) Insufficient Teacher Training
   One of the most pressing barriers is the readiness of teachers to embrace deep learning methods. Of the 10 STEM teachers interviewed, only 30% (3 teachers) felt adequately trained to implement these strategies confidently. Many shared that their training consisted of brief one- or two-day workshops without follow-up or in-class mentoring. A senior teacher confided, "I get the idea, but applying it in a class of 40 students is tough without real practice." This insight underscores a critical need for ongoing, hands-on professional development to empower educators in navigating this shift.
2) Infrastructure Limitations
   Another significant challenge is the limited access to supporting facilities, particularly computer labs and technology devices. Observations revealed that the school has only 10 laptops shared among 60 students in the program, compounded by unreliable internet connectivity. This led to delays in technology-driven projects like AI simulations or Python programming, which are central to the deep learning curriculum. During focus groups, students voiced their frustration, with one saying, "We're excited to learn coding, but we keep having to take turns, so it takes forever." This struggle is particularly pronounced in a regional context like Bengkulu, where school budgets for infrastructure often lag behind those in urban centers, amplifying the digital divide.
3) Resistance to Change
   The third challenge is resistance from some teachers, particularly those with more experience, to adopting new teaching methods. In interviews, two veteran teachers (with over 15 years of experience) expressed a preference for traditional, teacher-centered approaches like lectures and drills, finding them easier to manage and more aligned with national exam preparations. While they acknowledged the value of deep learning, they felt uneasy with its demand for constant flexibility and adaptation. Focus groups also revealed tensions between teachers eager for innovation and those more skeptical, which sometimes dampened collective morale. Observing this divide highlighted the discomfort of change, especially without adequate support or time to adjust.

To illustrate how these challenges are perceived across participants, the following table has been compiled based on interview and focus group data:

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Table 3. Distribution of Challenges in Deep Learning Implementation

| Challenge | Percentage of Teachers Reporting | Percentage of Students Reporting | Specific Context in Bengkulu |
|---|---|---|---|
| Insufficient Teacher Training | 70% (7 out of 10 teachers) | 40% (24 out of 60 students) | Training limited to short workshops |
| Infrastructure Limitations | 80% (8 out of 10 teachers) | 65% (39 out of 60 students) | Only 10 laptops for 60 students, unstable internet |
| Resistance to Change | 50% (5 out of 10 teachers) | 15% (9 out of 60 students) | Senior teachers prefer traditional methods |

This table 3 reveals that infrastructure issues are the most widely reported concern among both teachers and students, highlighting an urgent need for investment in resources, especially in regional schools like this one in Bengkulu. These challenges, if unaddressed, could hinder the long-term viability and scalability of the deep learning curriculum, a concern that remains at the forefront of this study.

**Discussion**

The findings in this study contribute to a consistent research theme advocating the utility of an immersive learning orientation in STEM education, as well as evidencing analogous long-standing concerns with the broader nature of education, such as in areas such as Bengkulu. Immersive learning strategies in a secondary school context The authors synthesize findings from the studies discussed with insights from the literature to enable an understanding of the impact of immersive learning strategies on student engagement, academic learning, and barriers to implementation in a particular secondary school. This dialogue serves to confirm, but also to position, these findings across global and local spectrums and to provide a nuanced view of the promise and limitations of this new curriculum. The strong increase in student motivation (82.5% enjoyed themselves very much [82.5%]) clearly relates to the results of Yang *et al*. (2020), who observed that an immersive learning approach to teaching in STEM education is more likely to support student engagement, by connecting theoretical content to practical, real-life applications. Taiwanese government policies and a case study of STEM education for Industry 4.0 underscore how a curriculum focused on critical thinking and problem solving increases students' personal investment in learning—a trend also reflected in this study from Bengkulu, where students reported that they had a better understanding of the relevance of their school-based learning. Furthermore, Sari (2025) highlighted immersive learning as a cornerstone of quality education, drawing attention to its emphasis on deep proficiency that transforms learners from observers to players (this became apparent during problem-based learning activities on themes such as plastic waste control that generated enthusiasm from young learners. Furthermore, the academic gains observed in this study, with a 35% increase in programming skills and a 30% increase in engineering design, support the claims made by Abdrakhmanov *et al*. (2024) who reported that technology embedding, namely computer vision and machine learning tools significantly improved the computational and technical skills of the participants. The researchers used python programming in a simple AI kit and studied interest-based self-directed learning in the field of STEM education, this study is in line with what students in Bengkulu schools use AI-based coding classes and complete tasks given to students in Bengkulu schools. Lohakan & Seetao (2024) also support this fact by reporting the success of running a large-scale experiment with AI kits to facilitate STEM skills of high school students, while they acknowledge that durable technological infrastructure is undoubtedly significant—the most frequent issue of concern in the challenges identified in our study. There are also parallels in the literature regarding the focus on interdisciplinary collaboration in curriculum design. Hu and Guo (2021) advocated for the design of STEM curriculum development that focuses on cross-disciplinary core competencies, which is reflected in the collaborative STEM Project on renewable energy by science, mathematics, and technology teachers in this school. Their study showed that integrating such knowledge resulted in a more complete understanding, as did the connected learning of Bangkulu students. In addition, Lin *et al*. (2025) provide examples from schools Taiwan where a pilot of collaborative STEM provision policy progressed positively, but was expensive in terms of the (necessary) coordination required of teachers—evident in the (critical but exhausting) weekly meetings that emerged from the experience.

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Despite the positive outcomes, the challenges identified in this study echo those documented in prior research, underscoring systemic issues that transcend local boundaries. The insufficient teacher training, reported by 70% of the interviewed teachers, aligns with findings by Farwati *et al*. (2021), who conducted a scoping review of STEM education implementation in Indonesia and identified a pervasive lack of professional development as a major barrier. Their analysis revealed that many Indonesian educators feel unprepared to adopt innovative pedagogies like deep learning without sustained training, a sentiment echoed by the teachers in Bengkulu who struggled to apply these methods in large classrooms. Cahyanti *et al*. (2024) further reinforce this in their systematic review of STEM education in Indonesian high schools, noting that limited teacher readiness often hampers the effective delivery of modern curricula, suggesting a need for long-term, practice-based professional development programs. Infrastructure limitations, cited by 80% of teachers and 65% of students in this study, also mirror challenges highlighted in the literature. Mulyani (2019) discusses the necessity of adequate facilities to support STEM learning in the context of Industry 4.0, pointing out that many Indonesian schools, especially in regional areas, lack the technological resources needed for hands-on, technology-driven education. This is strikingly relevant to the Bengkulu context, where only 10 laptops were available for 60 students, coupled with unreliable internet connectivity, stalling progress in critical areas like programming and AI simulations. Similarly, Mu'minah (2021) notes in her literature study on 21st-century learning through STEAM approaches that infrastructure deficits in rural and semi-urban settings often undermine the potential of innovative curricula, a reality that resonates deeply with the findings here. Resistance to change among educators, particularly senior teachers, as observed in 50% of the interviewed staff, is another recurring theme in STEM education research. Ordanovska *et al*. (2023) explore the implementation of STEM education in general institutions and identify cultural and professional resistance as a significant obstacle, especially among teachers accustomed to traditional, teacher-centered methods. Their findings suggest that such resistance often stems from discomfort with pedagogical shifts and alignment with standardized testing priorities, a pattern reflected in the preference of some Bengkulu teachers for conventional approaches due to national exam pressures. Olabe *et al*. (2018) add to this discussion by emphasizing the need for gradual cultural shifts and supportive policies to ease teachers into new methodologies, highlighting that without such support, resistance can impede curriculum reform—a critical insight for understanding the tensions observed in this study's focus groups.

While global and national studies provide a broad backdrop, the specific context of Bengkulu adds unique dimensions to these findings. The researcher notes that the local cultural emphasis on community issues, such as waste management in traditional markets, enriched problem-based learning projects by making them directly relevant to students' lives—a factor less frequently highlighted in international studies like those of Yang *et al*. (2020) or Lohakan and Seetao (2024), which often focus on urban or industrialized settings. This alignment with local challenges not only boosted engagement but also fostered a sense of agency among students, suggesting that deep learning curricula may have heightened impact when tailored to regional realities, as also hinted at in Mulyani (2019) discussion of contextual STEM approaches in Indonesia. Furthermore, the pronounced infrastructure challenges in Bengkulu, compared to more resource-rich urban schools often studied in works like Lin *et al*. (2025), underline disparities within national education systems. Cahyanti *et al*. (2024) touch on such regional inequities in their review, advocating for targeted policy interventions to bridge the digital divide—an urgent need in this case, where limited laptops and unstable internet hindered technology-enhanced learning. This local lens also amplifies the significance of teacher training gaps; as Farwati *et al*. (2021) note, regional educators often receive even less access to professional development than their urban counterparts, a disparity evident in the short, standalone workshops described by Bengkulu teachers.

The convergence of this study's findings with existing literature suggests several implications. First, the success of deep learning in enhancing motivation and academic outcomes, as supported by Yang *et al*. (2020) and Sari (2025), indicates that such approaches should be scaled across STEM programs, but with careful attention to contextual adaptation as emphasized by Mulyani (2019). Second, the shared challenge of teacher training, echoed in Farwati *et al*. (2021) and Cahyanti *et al*. (2024), calls for investment in continuous, hands-on professional development, potentially through mentorship models or peer-learning networks that could address the specific needs of regional educators like those in Bengkulu. Third, the infrastructure barriers, consistent with Mu'minah (2021), highlight the necessity of policy-driven resource allocation to ensure equitable access to technology, particularly in underserved

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areas—a point critical for the sustainability of deep learning initiatives. Additionally, the resistance to change observed aligns with Ordanovska *et al*. (2023), suggesting that future efforts should focus on gradual integration, supported by incentives and dialogue to bridge generational and methodological divides among educators. Rabinowitz *et al*. (2025) offer a complementary perspective through their study of machine learning-integrated science curricula, proposing that informal learning settings could serve as low-pressure environments to test and refine deep learning approaches before full classroom adoption—an idea worth exploring in the Bengkulu context to ease teacher transitions. The findings from this Bengkulu high school study both confirm and expand upon existing research on deep learning in STEM education. The positive impacts on student engagement and academic performance validate the approaches advocated by scholars like Yang *et al*. (2020), Abdrakhmanov *et al*. (2024), and Sari (2025), while the challenges of teacher training, infrastructure, and resistance resonate with barriers identified by Farwati *et al*. (2021), Mulyani (2019), and Ordanovska *et al*. (2023). The local context of Bengkulu adds depth to these discussions, emphasizing the importance of tailoring educational innovations to cultural and systemic realities. By situating these results within a broader scholarly framework, the researcher aims to contribute to a more nuanced understanding of how deep learning can transform STEM education, provided that systemic supports are strategically aligned to overcome entrenched obstacles.

## Conclusion

According to a study in a high school in Bengkulu, the implementation of an immersive learning curriculum in STEM learning had a significant impact on several student learning devices. The academics said that the method was successful, resulting in increased student motivation (reported by 82.5% of students) and increased learning of STEM concepts, as indicated by an average difference of 20-35% between students' pre- and post-test scores in programming and engineering design. In addition, 21st-century skills, particularly in collaboration and problem-solving, showed a significant increase, with teamwork skills among students jumping 27.5% according to a group project evaluation. Barriers including teacher unpreparedness (70% of teachers stated they were not equipped to take on the teaching method), low-level student technology infrastructure (only 10 laptops for 60) and some resistance from teachers to introducing one-to-one computer-based teaching, if not addressed, could prevent the program from reaching its full potential. Therefore, this study proposes several strategic actions to sustain the immersive learning curriculum in STEM education and its scale in Indonesia. First, there is a need for regular continuing professional development (CPD) for our STEM educators on the philosophy of deep learning in practice; that is, what it is, and how to do it. Second, the Government should invest more in school infrastructure, particularly in technology labs and proper internet connectivity to enable students to maximize the use of technology tools such as Python programming software and artificial intelligence (AI) tools. The third preference with regards to the VK2016 AID material is the development of a national curriculum that encourages the explicit inclusion of DL practices in STEM teaching (as a global policy intervention against preference 2) where the policy also facilitates (contextual) adaptation at a regional level such as the Bengkulu region with limited resources. If these barriers can be addressed through these suggested aspects, deep learning can reform STEM education in Indonesia in terms of preparing young people to meet future demands, through comprehensive understanding and appropriate skills.

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