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Stem-Based Learning Leadership in Elementary Schools

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Abstract

Indonesian learning, the Science, Technology, Engineering, and Mathematics (STEM) approach is recommended as a strategy to improve the quality of education towards a Golden Indonesia, but its implementation is still not optimal. This study aims to develop a STEM-based learning leadership design in elementary schools. The research method uses the ADDIE development design. At the need analysis stage with 120 elementary school principals as subjects, it showed that 67% experienced difficulties in leading STEM integration in learning. The STEM-based learning leadership design consists of 5 aspects, namely leadership in developing a STEM learning environment with local phenomena and establishing a STEM center in schools; leading the planning and implementation of STEM-based learning by applying a project-based learning model; leading reflection on improving the quality of learning; leading the involvement of parents as mentors and STEM learning resources. The results of the model design test from the expert and practitioner groups were in the very feasible category with an average feasibility percentage of 85.68%. At the implementation stage, the response of the principal as a user to the model design was 84.97% in the very satisfied category.

Keywords: *Innovation; Learning Leadership; Deep Learning; STEAM; Elementary Schools*

Introduction

In the pursuit of Indonesian Golden 2045, Indonesia is projected to have a population of more than 320 million people, predominantly within the productive age group, as a result of the demographic dividend. This demographic advantage provides a substantial opportunity to accelerate national development. Nevertheless, the demographic dividend can only be transformed into a sustainable competitive advantage if the Indonesian workforce is equipped with essential 21st-century competencies, particularly the 4C skills of critical thinking, creativity, communication, and collaboration**.** Consequently, the education system must foster learning environments that develop these competencies, enabling students to effectively respond to the complex challenges of the 21st century [1], [2].

Indonesia's education system is currently facing a serious challenge known as *learning loss*. This phenomenon is characterized by a decline in students' learning motivation, comprehension of subject matter, and academic performance. If not addressed effectively, learning loss may hinder the development of essential competencies and negatively affect students' long-term educational outcomes. [3]. The consequences of this condition are evident not only in students' declining academic performance but also in the insufficient development of critical thinking skills, one of the key competencies required in the 21st century. Consequently, there is a need for innovative learning leadership that facilitates the implementation of *deep learning* and the STEAM (*Science, Technology, Engineering, Arts, and Mathematics*) approach. These approaches enable students to actively participate in meaningful learning experiences, address authentic problems, and continuously enhance their critical thinking abilities, preparing them to meet the demands of an increasingly complex and dynamic world.

On the other hand, Indonesia is facing a rapid educational transformation driven by technological advancement, globalization, and the changing demands of the 21st century. This situation requires immediate responses from educational leaders, particularly in ensuring the provision of high-quality learning services. Educational leaders play a crucial role in preparing learning processes that equip students with the knowledge, skills, and competencies needed to remain competitive in the future. However, the results of the 2022 Programme for International Student Assessment (PISA) placed Indonesia below the OECD average in reading, mathematics, and science performance. These international comparative findings highlight persistent challenges in the quality of learning and the development of higher-order thinking skills among Indonesian students. Therefore, strategic innovations in learning leadership are essential to improve educational quality and prepare students to thrive in an increasingly complex global environment [4].

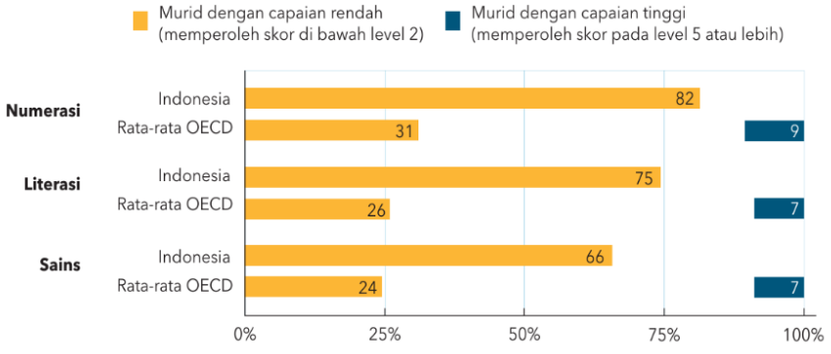

Fig. 1. Percentage of Students Reaching the Minimum Proficiency Level (Level 2 and Above) in PISA 2022 (Source: OECD, 2023)

Figure 1 illustrates the percentage of students achieving proficiency Level 2 or above in PISA 2022. Indonesia's performance remains below the OECD average, indicating persistent challenges in learning quality and the development of higher-order thinking skills. These findings underscore the importance of implementing innovative learning leadership and student-centered instructional approaches to improve educational outcomes. The PISA 2022 assessment revealed a substantial gap in Higher-Order Thinking Skills (HOTS) among Indonesian students. Only 18% of students attained at least Level 2 proficiency in mathematics, compared to 25% in reading and 34% in science. These results suggest that many students have not yet developed the minimum competencies required to effectively analyse information, reason critically, and solve authentic problems. Similarly, students' performance in creative thinking was relatively low, indicating challenges in generating innovative ideas and solutions. Such findings underscore the necessity of strengthening learning practices that promote critical and creative thinking as essential competencies for the 21st century [4]. These findings indicate that learning practices in elementary schools have not yet adequately fostered Higher-Order Thinking Skills (HOTS), which are crucial for success in the 21st century. Consequently, there is a pressing need for innovative educational approaches that provide meaningful learning experiences and encourage active student participation. Learning should move beyond the transmission of knowledge toward engaging students in authentic problem-solving, inquiry, collaboration, and reflection. In this regard, the integration of *deep learning* and the STEAM approach offers a promising framework for cultivating critical thinking, creativity, and lifelong learning skills among elementary school students.

In 2022, Indonesia introduced the *Merdeka Curriculum* as part of its educational reform efforts to enhance learning quality and student competencies. Subsequently, in 2025, the curriculum was strengthened through the adoption of a *deep learning* approach. This approach emphasizes meaningful, contextual, and participatory learning experiences aimed at developing Higher-Order Thinking Skills (HOTS) from an early age. Through deep learning, students are encouraged not only to acquire knowledge but also to analyse, evaluate, and apply their understanding in authentic contexts, thereby fostering critical thinking, problem-solving, creativity, and lifelong learning competencies [5]. These objectives can be achieved through the use of open-ended questions, meaningful discussions, and the exploration of authentic real-world problems. Such learning activities encourage students to actively construct knowledge, reflect on their understanding, and apply concepts in relevant contexts, thereby fostering critical thinking and deeper learning.

In 2025, the Indonesian government recommended the Science, Technology, Engineering, and Mathematics (STEM) approach as a strategic framework for improving educational quality in support of the Golden Indonesia 2045 vision. Furthermore, STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning integrated with interactive media is widely regarded as an effective strategy for fostering critical thinking, creativity, and innovation from an early age. By combining interdisciplinary knowledge with engaging learning experiences, the STEAM approach encourages students to explore, create, solve problems, and develop the competencies needed to thrive in the 21st century [6], [7]. The integration of Arts into the STEM framework has led to the emergence of STEAM (Science, Technology, Engineering, Arts, and Mathematics), a more comprehensive approach that not only enhances logical thinking and problem-solving skills but also promotes creativity, innovation, and design thinking. Consequently, STEAM is regarded as a more effective approach for fostering the holistic development of twenty-first-century competencies.

Contemporary challenges in Indonesian primary and secondary education extend beyond improving school management quality to ensuring the effective implementation of student-centered learning. Consequently, school principals are required to move beyond traditional administrative and managerial roles and adopt *learning leadership* practices that guide, support, and improve instructional quality. Research has demonstrated that effective learning

leadership positively influences student achievement and facilitates the development of key 21st-century competencies, such as critical thinking, creativity, communication, and collaboration. Therefore, strengthening learning leadership is essential for creating meaningful learning experiences and enhancing students' readiness to face future educational and societal challenges [8], [9]. Hattie emphasized that meaningful and student-centered learning has a significant impact on students' academic achievement and the long-term development of learning capabilities. Such learning experiences enable students to actively engage in the construction of knowledge, deepen their understanding of concepts, and develop the cognitive skills necessary for lifelong learning. [10]. Furthermore, Hoskins and Fredriksson argued that the development of higher-order thinking skills should begin in primary education, as this stage represents a critical period for cultivating reflective thinking, problem-solving abilities, and deep learning. These competencies serve as essential foundations for students' future academic success and their ability to adapt to increasingly complex learning environments. [11]. Previous studies have demonstrated that learning leadership, deep learning approaches, and STEAM-based learning, when implemented separately, can improve the quality of learning and students' competencies. However, studies integrating learning leadership, deep learning principles, and the STEAM approach into a comprehensive model for elementary schools remain limited. Furthermore, few studies have developed a learning leadership model specifically designed to enhance elementary school students' critical thinking skills through the integration of deep learning and STEAM.

The novelty of this study lies in the development of a STEAM-based learning leadership model that integrates the principles of deep learning, namely meaningful, mindful, and joyful learning, into learning planning, implementation, reflection, evaluation, and the development of student-centered learning environments to improve elementary school students' critical thinking skills. This study is expected to contribute both theoretically and practically. Theoretically, it enriches the literature on STEAM-based learning leadership and deep learning. Practically, the proposed model can serve as a guideline for school principals and teachers in managing learning processes that are oriented toward the development of students' critical thinking skills. This study aims to: (1) analyse the need for STEM-based learning leadership in elementary schools; (2) develop a STEM-based learning leadership model for elementary schools; and (3) evaluate the practicality and effectiveness of the developed STEM-based learning leadership model in enhancing students' critical thinking skills.

Method

This study employed a Research and Development (R&D) approach using the ADDIE model [12], [13]. The research was conducted in accredited A-level public and private elementary schools in Kudus Regency, Indonesia. The data sources included school principals, teachers, and students. Data were collected through classroom observations, interviews, and questionnaires. The development process involved two learning experts and two STEM experts from Pendidikan Indonesia University as expert validators. Data were analyse using both quantitative and qualitative approaches.

The product developed in this study was a STEM-based learning leadership model for elementary schools. The ADDIE model proposed by Dick and Carey consists of five development stages: Analysis, Design, Development, Implementation, and Evaluation. During the analysis stage, needs and challenges related to STEM-based learning leadership were identified. The design stage focused on developing the components and framework of the model. The development stage involved expert validation and model revision. Subsequently, the implementation stage tested the model in selected schools, while the evaluation stage assessed the practicality, feasibility, and effectiveness of the model. The research procedure is illustrated in Figure 2.

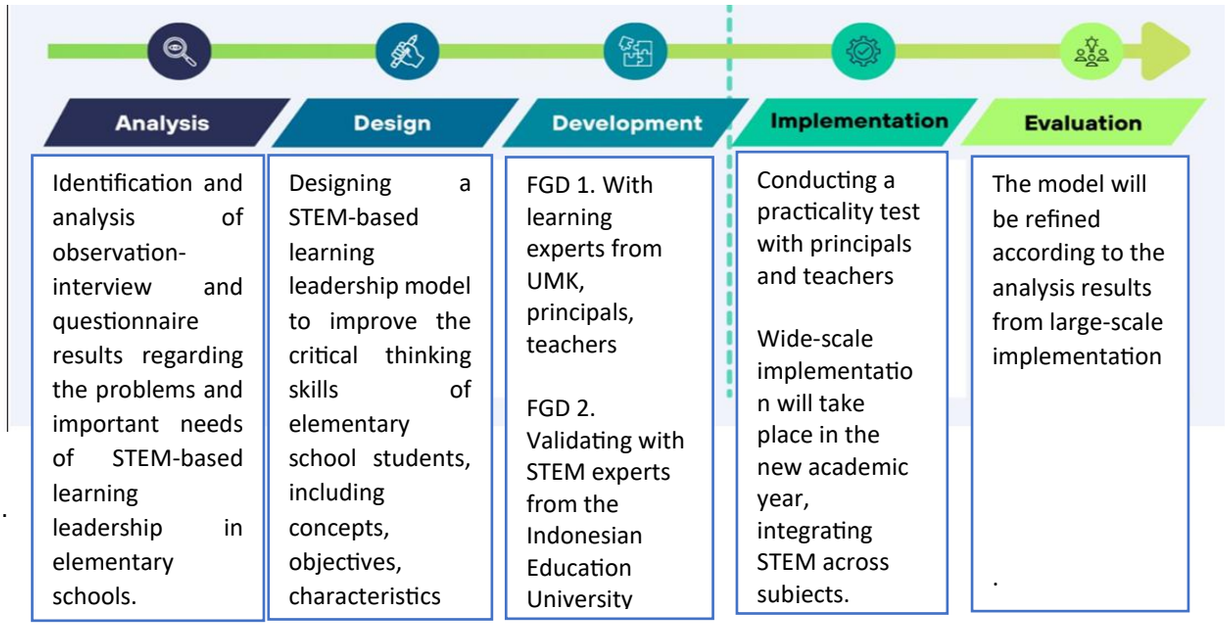

Fig. 2. ADDIE Model Research Procedure

Results

Analysis

Field observations indicate that many teachers have implemented the STEM approach but lack understanding. Interviews with teachers revealed that they are happy to implement the STEM approach, but it requires considerable preparation, infrastructure, and time. Furthermore, teachers must complete the material. A needs analysis involving 120 elementary school principals found that 67% experienced difficulties leading STEM integration in learning. Observation and interviews revealed that 72% of teachers had difficulty integrating STEM into deep learning.

The integration of Arts into the STEM framework has led to the emergence of STEAM (Science, Technology, Engineering, Arts, and Mathematics), which offers a more comprehensive and holistic learning experience [14]. The STEAM approach not only focuses on developing logical thinking, technological literacy, engineering design, and mathematical problem-solving skills, but also fosters creativity, imagination, aesthetics, and design thinking [15]. The inclusion of Arts enables students to connect knowledge across disciplines, generate innovative solutions, and express ideas in more meaningful ways. Previous studies have shown that STEAM-based learning can enhance critical thinking, creativity, collaboration, and problem-solving skills, which are essential competencies for the twenty-first century [16]. Furthermore, STEAM encourages students to engage in authentic, contextual, and interdisciplinary learning experiences, thereby supporting balanced cognitive, affective, and psychomotor development [17]. Therefore, STEAM is considered a more appropriate approach for fostering twenty-first-century competencies in a holistic manner and preparing students to face increasingly complex, dynamic, and technology-driven global challenges [18]. However, the successful implementation of STEAM in schools depends not only on teachers' competencies but also on the ability of school principals to exercise effective learning leadership that guides the planning, implementation, reflection, and evaluation of learning processes on an ongoing basis. Therefore, a STEAM-based learning leadership model is needed to support the implementation of deep learning and enhance elementary school students' critical thinking skills. Previous studies have shown that the integration of technology in learning supported by a sustainable pedagogical framework can enhance student engagement and improve the quality of the learning process [19]. The effective learning management through the use of interactive digital worksheets has been proven to significantly improve students' critical thinking skills and learning outcomes [20]. These findings indicate that innovative learning management and instructional leadership play an important role in creating meaningful learning experiences and fostering students' higher-order thinking skills.

Desain:

- A learning leadership model was developed by integrating the STEM approach.
- Learning leadership applies the management functions of planning, implementation, and evaluation.

- STEM-Based Learning Leadership integrates the principles of deep learning and STEM learning.
- Component 1. Leading the Development of a Student-Oriented Learning Environment.
- Component 2. Leading learning planning, starting with Identifying Problems and Potential, analysing Learning Outcomes (CP) and STEM integration across subjects, establishing STEM projects, and developing learning designs (learning objectives, assessments, activities, environment, and partnerships).
- Component 3. Leading learning implementation by applying the principles of deep learning: Meaningful, Joyful, and Mindful. The learning steps are: 1) Problem and potential analysis; 2) Investigation: designing a design or solution; 3) Testing and shared understanding; 4) Formative and summative assessment
- Component 4. Leading learning evaluation and reflection to determine the achievement of learning objectives and obstacles.
- Component 5, Leading STEM center as part of a learning community for professional development and improving the quality of student learning

Development. The model design was developed collaboratively with experts and practitioners through focus group discussions. Input was obtained for the following components:

1. Leading the development of the learning environment is initially included in the planning phase. It is best to lead efforts to develop a safe and comfortable environment for students before planning.
2. Management functions were removed.
3. Local phenomena should be given more attention to identifying problems and potential.
4. Implementation of STEM-based learning by implementing a project-based learning model elaborated on STEM learning principles.
5. Additionally, leading parent involvement as mentors and resources for STEM learning.

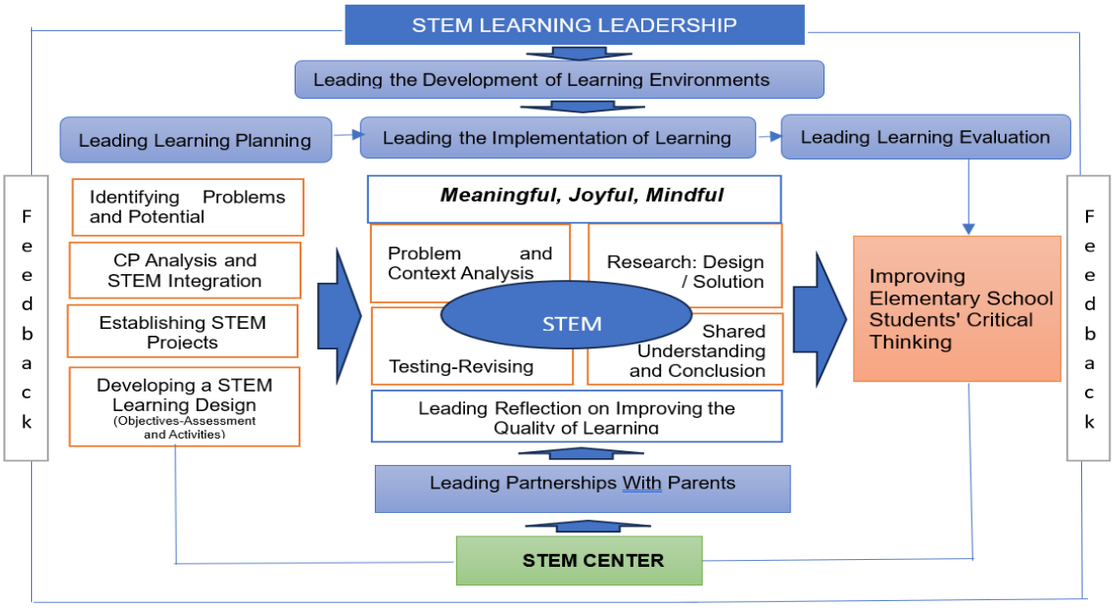

Fig. 3. Model Kepemimpinan Pembelajaran Berbasis STEM

The STEM-Based Learning Leadership Model developed in this study underwent several revisions based on expert validation and practitioner feedback. The final model consists of the following components and aspects:

1. Leading the Development of a Student-Centered Learning Environment
   School leaders are responsible for creating and fostering a learning environment that places students at the center of the learning process, encouraging active engagement, collaboration, and meaningful learning experiences.

2. Leading Learning Planning, which includes:
   a) Identifying School Characteristics, Problems, and Potentials. These three aspects provide a comprehensive understanding of the school context. The results of the identification process are analyzed and prioritized to determine the key challenges and potentials that need to be addressed and developed.
   b) Analyzing Learning Outcomes and Integrating STEM Components into Subject Content. This process ensures alignment between curriculum objectives, STEM components, and subject matter.

c) Determining STEM Project Topics. Project topics are selected based on the results of the identification process and the analysis of learning outcomes.
d) Designing STEM Learning. This stage involves establishing learning objectives, assessment strategies, and instructional procedures while incorporating scientific and engineering practices. Learning objectives are derived from the analysis of learning outcomes and selected projects. Assessment strategies are aligned with the intended learning objectives. The instructional design consists of four learning stages.

3. Leading Learning Implementation
The implementation process integrates the principles of Deep Learning *Meaningful, Joyful, and Mindful Learning* with the core principles of STEM education, namely problem-solving, scientific and engineering practices, and interdisciplinary integration. Learning activities emphasize responsible and conscious problem-solving, focusing on authentic issues that are relevant and beneficial to the community in which students live. Scientific and engineering practices are conducted in a meaningful and enjoyable manner, enabling students to develop self-regulation and recognize the relevance of what they learn to everyday life. The learning process follows four stages:
a) Analysis of problems and potentials
b) Investigation and solution design
c) Testing and revision; and
d) Shared understanding and conclusion

4. Leading Reflection to Improve Learning Quality
School leaders facilitate reflective practices among teachers and students to continuously improve the quality of teaching and learning processes.
5. Leading Parent Partnerships
Parents are encouraged to participate directly as learning resources and mentors or indirectly by providing support for students' learning activities.
6. Leading the Evaluation of STEM Learning Programs
School leaders evaluate STEM learning programs to determine their effectiveness in improving elementary school students' critical thinking skills. This evaluation can be conducted through the analysis of students' summative assessment results and other relevant performance indicators.
7. Establishing a School STEM Center
A STEM Center is established within the school as a professional learning community that supports teacher professional development, collaboration, innovation, and the continuous improvement of student learning quality.

The developed STEM-Based Instructional Leadership Model is strengthened by six main, interrelated components. First, student-centered learning positions students as active agents in constructing their knowledge and learning experiences [21]. Second, the principle of deep learning comprising meaningful, mindful, and joyful learning aims to foster deep conceptual understanding that is reflective and meaningful [21]. Third, STEM learning characteristics emphasize problem-solving, scientific and engineering practices, and interdisciplinary integration to develop students' critical thinking and creativity skills [22]. Fourth, learning leadership plays a role in directing, facilitating, monitoring, and continuously evaluating the learning process to improve student learning quality [23]. Fifth, parental partnership provides support for the learning process both as a learning resource and as a companion in project-based activities, making learning more contextual. Sixth, the establishment of a STEM Center serves as a professional learning community that supports teacher collaboration, competency development, and the sustainability of instructional innovation in schools [24]. The integration of all these components forms a learning ecosystem that supports the implementation of STEM based on deep learning to enhance the critical thinking skills of elementary school students.

Implementation and Evaluation. The practicality test conducted by a panel of experts and practitioners indicated that the STEM-Based Learning Leadership Model was categorized as highly feasible, achieving an average feasibility score of 85.68%. This result suggests that the developed model possesses a high level of practicality, making it easy to understand and implement within elementary school settings. According to Nieveen, the quality of an educational model is determined by three main criteria: validity, practicality, and effectiveness [25]. During the implementation phase, the response from school principals as the primary users of the model reached 84.97%, which was categorized as very satisfactory. This high level of user satisfaction indicates that the model provides clear guidance for implementing STEM-based learning leadership practices. User acceptance is considered one of the key indicators of the successful implementation of an educational innovation [26]. The implementation results also revealed that learning leadership plays a significant role in improving the quality of the teaching and learning process. Effective learning leadership focuses on developing an academic vision, supporting teachers, and continuously monitoring instructional practices [27]. Within the developed model, school principal function as facilitators who support the implementation of STEM learning, thereby fostering a more innovative and student-

center learning environment. The integration of STEM learning within the model supports the development of twenty-first-century skills, including critical thinking, creativity, collaboration, and problem-solving. Integrated STEM learning enables students to connect concepts from multiple disciplines to address real-world problems effectively [28]. Therefore, the developed model contributes not only to improving the quality of instruction but also to enhancing students' competencies required for future challenges. However, the model can still be further refined through strengthening teachers' STEM-related competencies, optimizing the role of the STEM Center, and enhancing partnerships with parents and the broader community. Continuous improvement is essential to ensure that educational innovations remain relevant to evolving school needs and societal changes[29].

Conclusion

A STEM-based learning leadership model is urgently needed in elementary schools. This model serves as a guide for leading learning management, adhering to the principles of deep learning and STEM learning. The STEM-based learning leadership model consists of seven components: Component 1) Leading the Development of a Student-Oriented Learning Environment; 2) Leading learning planning; 3) Leading learning implementation; 4) Leading reflection to improve the quality of learning; 5) Leading partnerships with parents; 6) Leading evaluation of STEM learning; 7) Leading STEM centers as part of a learning community for professional development and improving the quality of student learning. Each component has its own aspects.

Recommendation: The model can be implemented by principals or teachers and can be further developed for further research by integrating digital media such as robotics and AI.

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