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.Integrating Deep Learning-Based STEM Education to Enhance 21st-Century Skills among Generation Z

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Abstract

21st century education requires mastery of critical thinking, creativity, communication, collaboration, and digital literacy skills, especially for Generation Z who are growing up amid technological developments. One relevant learning strategy is the integration of Science, Technology, Engineering, and Mathematics (STEM) with a deep learning approach that focuses on conceptual understanding, reflection, and active student engagement. This article aims to review recent national and international research on the application of deep learning-based STEM integration in improving 21st-century skills in Generation Z. The method used is a systematic literature review (SLR). Relevant articles were analyzed thematically, highlighting the implementation of STEM, the application of deep learning, its impact on 21st-century skills, and its relevance to the characteristics of Generation Z. The results of the study show that the integration of STEM with deep learning contributes to improving scientific process skills, problem solving, collaboration, and digital literacy, and is capable of creating contextual, innovative learning that is in line with future needs. Thus, this approach is an effective strategy in facilitating the mastery of 21st-century skills while preparing Generation Z to face global challenges.

Keywords ; STEM education, deep learning, 21st-century skills, generation Z.

INTRODUCTION

The rapid advancement of globalization and the Fourth Industrial Revolution has brought significant transformations across various aspects of life, including education. A well-managed education system plays a crucial role in producing high-quality and competitive human resources (Nya'dhin et al., 2024). In this context, the curriculum serves as a vital foundation for achieving educational goals. Without a well-structured

curriculum, the learning process will struggle to achieve its intended outcomes effectively (Kusumawardani et al., 2024).

Generation Z, who grew up in the digital era, is required to master 21st-century skills such as critical thinking, creativity, communication, collaboration, digital literacy, as well as problem-solving and decision-making abilities (Trilling & Fadel, 2021; Ledoh et al., 2024). These competencies are essential assets for navigating global challenges that are increasingly complex, dynamic, and uncertain.

Therefore, educational innovations are needed that not only emphasize knowledge acquisition but also integrate skills and attitudes within real-world contexts (OECD, 2020). Teaching methods become a key instrument for teachers in achieving learning objectives through well-planned and structured activities (Sabariyah et al., 2024). One relevant approach to address this demand is deep learning. This approach not only focuses on mastering conceptual knowledge but also holistically develops students' cognitive, affective, and psychomotor competencies (Waruwu, 2025).

Deep learning encourages students to understand concepts in depth, connect them with prior experiences, and foster reflective thinking (Fullan & Langworthy, 2019). Its strength lies in its flexibility and adaptability, allowing integration with other learning models such as problem-based learning, project-based learning, inquiry-based learning, and collaborative learning to create more meaningful learning experiences.

Meanwhile, the STEM (Science, Technology, Engineering, and Mathematics) approach has also proven effective in preparing future generations. STEM emphasizes the integration of multiple disciplines to solve problems creatively, practically, and collaboratively (Bybee, 2020). However, its successful implementation depends greatly on effective instructional design. Abas et al. (2024) note that STEM can be implemented through various approaches, including problem-based learning, project-based learning, inquiry-based learning, game-based learning, digital-based learning, collaborative learning, and practice-based learning.

The integration of STEM with deep learning has emerged as a relevant solution to enhance educational quality, particularly for Generation Z, who are accustomed to digital technology and tend to learn visually (Hidayat & Suprapto, 2022). Research findings indicate that combining these two approaches strengthens scientific process skills, digital literacy, problem-solving abilities, and collaborative attitudes among students (Rahmawati et al., 2021; Nugroho & Setiawan, 2023). Therefore, examining the integration of STEM and deep learning is essential in providing a comprehensive understanding of its effectiveness in preparing younger generations to meet the demands of the 21st century.

This article aims to review various studies on the implementation of deep learning-based STEM education in the context of 21st-century learning. Through this review, it is expected to provide both conceptual and practical contributions in formulating innovative, contextual, and future-oriented learning strategies to strengthen 21st-century skills, particularly for Generation Z, enabling them to face increasingly complex global challenges.

METHOD

This study applies a systematic literature review (SLR) approach to examine various studies discussing the integration of deep learning-based Science, Technology, Engineering, and Mathematics (STEM) learning in the development of 21st-century skills in Generation Z. Literature sources were obtained from Google Scholar, ResearchGate, and Portal Garuda (SINTA) using the keywords "STEM Education," "Deep Learning," "21st Century Skills," and "Generation Z" with a publication range of 2019–2025. The articles considered were relevant national and international journal publications, available in full text, and addressing the implementation of STEM, the application of deep learning, and the strengthening of 21st-century skills. Publications in the form of non-peer-reviewed proceedings and articles outside this period were not included.

The selection process was carried out by reviewing the titles, abstracts, and content of the articles to ensure topic relevance. The data obtained was analyzed thematically by grouping the research findings based on four main focuses, namely the application of STEM, the application of deep learning, its influence on 21st-century skills, and its relationship with the characteristics of Generation Z. The results of the study were then summarized in the form of a narrative synthesis that provides a comprehensive understanding of the direction of development, obstacles, and prospects for the implementation of deep learning-based STEM learning in the digital era.

RESULT AND DISCUSSION

The results of a literature review using the systematic literature review method show that the integration of deep learning-based STEM learning contributes significantly to strengthening 21st-century skills in Generation Z. In general, the studies analyzed confirm that this approach is effective in developing critical thinking, problem solving, creativity, communication, collaboration, and digital literacy skills. A number of studies (Novitasari et al., 2025; Rahmawati et al., 2021; Nugroho & Setiawan, 2023) emphasize that the application of deep learning in the STEM framework not only deepens conceptual understanding but also directs students to apply their knowledge in real contexts through experimentation, problem solving, and digital collaboration.

The analysis also shows that the integration of STEM with deep learning plays an important role in strengthening science process skills. This is demonstrated by the research of Rahmawati et al. (2021), which found an increase in the ability to formulate hypotheses, design experiments, and analyze data. Furthermore, Nugroho & Setiawan (2023) reported that this model improves high school students' digital literacy and collaborative skills, which is in line with the characteristics of Generation Z who are accustomed to technology. Similar results were also obtained from the research by Zakhrofa & Setiaji (2023), which stated that STEM learning is more effective than conventional methods in improving learning activities and outcomes.

Other studies (Asrizal et al., 2023; Ichsan et al., 2023; Suwardi, 2021) confirm that the STEM approach supports the strengthening of 21st-century skills across

disciplines, while Hardian et al. (2025) add that deep learning not only develops higher-order thinking skills but also contributes to the formation of positive character traits in students. From an international perspective, Fullan & Langworthy (2019) highlight that deep learning emphasizes deep conceptual understanding and reflective skills, while Hidayat & Suprapto (2022) emphasize the relevance of learning to authentic everyday problems. Ichsan et al. (2023) even report an increase in 21st-century skills with a high N-Gain value (0.86), confirming the effectiveness of deep learning-based STEM integration.

In addition, literature reviews show that the integration of STEM and deep learning encourages cross-disciplinary collaboration and strengthens creativity. Bybee (2020) asserts that STEM naturally directs students toward multidisciplinary problem solving, while deep learning adds a reflective and emotional dimension to learning. Kurniawati & Sari (2022) found that the application of deep learning-based STEM projects at the junior high school level can enhance creativity and the ability to design innovative solutions to environmental problems.

Based on the synthesis of these findings, it can be concluded that the integration of STEM with deep learning is an effective pedagogical strategy in strengthening the 21st-century skills of Generation Z. This model is not only oriented towards academic mastery but also provides contextual, meaningful learning experiences that are relevant to the demands of the future. The practical implication is that teachers need to design project-based interdisciplinary learning and encourage reflective engagement among students, so that 21st-century skills can develop optimally.

CONCLUSION

Based on a literature review, integrating STEM learning with a deep learning approach has been proven to be an effective strategy in developing 21st-century skills in Generation Z. This approach not only emphasizes academic mastery but also strengthens essential skills such as critical thinking, problem solving, creativity, communication, collaboration, digital literacy, and positive character building. Research evidence shows that the combination of STEM and deep learning can deliver more contextual, authentic problem-based learning that is relevant to everyday life, thereby encouraging active and reflective engagement among students. In addition, the integration of these two approaches supports cross-disciplinary collaboration, facilitates the development of innovative solutions, and fosters the reflective skills needed to face the complexities of the 21st century.

Therefore, teachers have an important role in designing project-based, problem-solving-oriented interdisciplinary learning so that deep learning-based STEM integration can become a strategic foundation for preparing Generation Z to face global challenges.

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