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Integration of STEM-Based Learning in Improving Critical Thinking in Mathematics Learning: a Bibliometric Analysis

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ABSTRACT

Objective: *This study aims to analyze global research trends on the integration of STEM-based learning to improve students' critical thinking skills in mathematics education during 2021–2025. It seeks to map publication growth, identify dominant keywords, and explore thematic relationships among research topics.* ***Method:*** *A bibliometric analysis was conducted using data from the Scopus database (2021–2025). The study followed five systematic stages: research design, data compilation, analysis, visualization, and interpretation. Keyword mapping was performed using VOSviewer software with terms such as "STEM," "education," "critical thinking," and "mathematics."* ***Results:*** *A total of 144 relevant articles were identified. The number of publications increased significantly from 2021 to 2025, with "STEM education" emerging as the most dominant keyword. Visualization revealed strong relationships among STEM education, critical thinking, problem solving, and collaborative learning, reflecting a growing global emphasis on developing 21st-century skills through contextual and project-based learning.* ***Novelty:*** *This study presents the first comprehensive bibliometric mapping focused on the intersection between STEM integration and critical thinking in mathematics education. It also highlights emerging research directions integrating digital technology and artificial intelligence (AI) into STEM learning to support innovative, future-oriented educational practices.*

INTRODUCTION

Critical thinking skills are among the higher-order cognitive abilities emphasized in 21st-century education frameworks. In mathematics learning, these skills involve not only conceptual understanding and procedural fluency but also the ability to analyze, evaluate, and connect mathematical ideas to solve problems logically and reflectively (Saxton et al., 2022). Despite their importance, various studies have shown that students' critical thinking skills remain below expectations. For instance, data from the Programme for International Student Assessment (PISA, 2022) revealed that Indonesian students ranked 71st out of 81 countries in mathematical literacy, indicating limited analytical and evaluative reasoning abilities (OECD, 2023). Similarly, Ilyas et al. (2022) found that many students tend to rely on memorization and teacher guidance, showing difficulty in making independent judgments during problem solving. Several studies have confirmed that STEM integration improves students' analytical and reflective abilities (Feziyasti et al., 2025; Lou et al., 2023).

Low performance in PISA, especially in mathematical literacy, underscores the need for pedagogical innovations, such as STEM integration, to develop analytical and problem-solving competencies. To address these challenges, the integration of STEM