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Effectiveness of STEM Based Differentiated Learning on Students Critical Thinking Skills In Higherd Education

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Abstrak

Penelitian ini bertujuan untuk mengetahui pengaruh pembelajaran differensiasi berbasis STEM untuk meningkatkan keterampilan berpikir kritis mahasiswa pada perguruan tinggi. Jenis penelitian adalah penelitian kuantitatif dengan pendekatan meta-analysis. Sampel penelitian berasal dari 12 jurnal nasional dan internasional terbitan 2022-2024 terindeks SINTA, Web of Science dan Scopus. Kriteria inklusi adalah penelitian harus relevan; penelitian diperoleh dari database Mendeley, ScienceDirect, Google Scholar dan ERIC, Penelitian harus metode eksperimen; penelitian memiliki data yang lengkap untuk menghitung nilai effect size serta ukuran sampel > 25 mahasiswa. Analisis data adalah analisis statistik kuantitatif dengan bantuan sofware JSAP. Hasil penelitian menyimpulkan bahwa pembelajaran differensiasi berbasis STEM memnerikan dampak positif untuk meningkatkan keterampilan berpikir kritis mahasiswa pada perguruan tinggi dengan nilai Hedge's (d)= 1.07dengan kategori effect size tinggi. Temuan menunjukan bahwa pembelajaran differensiasi efektif untuk diterap pada mahasiswa diperguruan untuk mendorong kemampuan berpikir kritisnya dalam proses pembelajaran.

Kata Kunci: Pembelajaran differensiasi; STEM; Berpikir Kritis; Meta-analysis

Abstract

This study aims to determine the influence of STEM-based differentiation learning to improve students' critical thinking skills in higher education. The type of research is quantitative research with a meta-analysis approach. The research sample came from 12 national and international journals published in 2022-2024 indexed by SINTA, Web of Science and Scopus. The inclusion criteria are that the research must be relevant; research obtained from Mendeley, ScienceDirect, Google Scholar and ERIC databases, Research must be an experimental method; The study has complete data to calculate the effect size value and sample size > 25 students. Data analysis is quantitative statistical analysis with the help of JSAP software. The results of the study concluded that STEM-based differentiation learning had a positive impact on improving students' critical thinking skills in higher education with Hedge's (d) = 1,07 with a high effect size category. The findings show that differentiation learning is effective to be applied to students in higher education to encourage their critical thinking skills in the learning process.

***Keywords**:* Differentiation learning; STEM; Critical Thinking; Meta-analysis

Introduction

In the context of higher education, critical thinking skills are an important asset that prepares students for success not only in the classroom, but also in a dynamic and often unpredictable work environment (Arisoy & Aybek, 2021; Zainil et al., 2022). Higher education serves as an important platform for developing these skills, given the increasing complexity and global challenges. Critical thinking skills enable students to analyze deeply, evaluate objectively, and create innovative solutions to complex problems (Nurtamam et al., 2023). Therefore, higher education institutions strive to design a curriculum that not only puts forward theoretical knowledge but also encourages critical analysis and independent problem-solving (Yaki, 2022). The importance of honing critical thinking skills in higher education is not only relevant from an academic point of view but also crucial for future professional success. In a fast-paced and ever-changing world of work, employees who are able to think critically, make informed decisions, and solve problems effectively are invaluable (Sarwi et al., 2024; Suwistika et al., 2024). Therefore, higher education must facilitate deep and differentiated learning that challenges students to step out of their comfort zones, thus allowing them to become independent and innovative thinkers who can adapt and thrive in a variety of situations.

The STEM learning approach is an approach that integrates the disciplines of Science, Technology, Engineering, and Mathematics, and has become a key component in the modern educational curriculum (Rachmadtullah et al., 2023). This approach aims to provide students with a holistic learning experience, connect theory with real practice, and strengthen their conceptual and applicative understanding. Through STEM, students not only learn scientific principles, but also develop essential skills such as problem-solving, critical thinking, and the ability to collaborate effectively (Pitorini et al., 2024; Pahrudin et al., 2021). This helps in preparing them for various challenges in a work environment that is based on technology and innovation. The relevance of STEM education in today's era is inseparable from the demands of the ever-evolving global job market that requires a workforce skilled in technology and innovation (Ijirana et al., 2022). The industry is currently looking for individuals who not only have technical knowledge, but are also capable of thinking innovatively and applying scientific solutions in real-world scenarios. Therefore, STEM education plays a crucial role in equipping students with the necessary skills and knowledge to face future challenges and bring about positive change. In this way, STEM not only enhances individual capabilities, but also drives economic growth and social progress on a global scale (Yıldırım et al., 2022).

Although the differentiated STEM learning approach is considered to have the potential to improve students' critical thinking skills, there are still a number of challenges that hinder its effectiveness in higher education. One of the main problems is the lack of adequate resources and training for lecturers and educators in implementing differentiated learning strategies. Many institutions are not yet fully equipped with the technology, teaching materials, and support necessary to provide a learning experience that is truly tailored to each student's needs. In addition, the lack of continuing professional training for educators hinders their ability to effectively apply differentiated learning methods in STEM curricula.

In addition, there are challenges in assessing the real impact of differentiated STEM learning on the development of critical thinking skills (Zulyusri et al., 2023; Sudrajat, 2023). The measurement and evaluation of critical thinking skills is often subjective and complex, making it difficult to objectively assess the effectiveness of these learning methods. Difficulties in standardizing teaching and assessment across STEM disciplines also add complexity in the implementation of differentiated learning strategies (Hariyadi et al., 2023). As a result, further research is needed to develop a valid and reliable assessment instrument to accurately measure the effect of differentiated learning on the improvement of critical thinking skills among higher education students (Ilma et al., 2020; Twaddle & Smith, 2023)

Differentiated learning is an educational approach that adapts the learning process to meet the unique learning needs of each student. This concept focuses on providing a variety of learning paths that allow all students to access the material according to their abilities, interests, and learning styles (Hacioglu & Gulhan, 2022). In this context, educators can customize content, processes, products, and learning environments,

so that every student gets an equal opportunity to grow. This approach is especially important in STEM learning, where the material is often complex and challenging. By implementing differentiated learning, educators can facilitate a deeper understanding and inspire interest and motivation in learning among students with various backgrounds and abilities (Pahrudin et al., 2021).

In the context of STEM learning, differentiated learning can be integrated through various methods (Çayır & Balcı, 2020; Arisoy & Aybek, 2021). For example, educators can use group-based projects that allow students to choose roles based on their strengths, or adapt lab experiments so that students can explore concepts at different levels according to their understanding (Patandung, 2023). Technology can also be leveraged to provide diverse learning resources, from digital simulations to interactive applications, which can be customized to support individual learning speeds. In this way, differentiated learning not only increases the effectiveness of STEM learning but also helps prepare students to become critical thinkers and efficient problem solvers in the future (Utami, 2023; Chukusol et al., 2024).

Research by Thompson and Williams (2019) at a leading university in the United States evaluated the implementation of differentiated learning methods in biotechnology courses. The results showed a significant improvement in students' analytical and evaluative abilities after taking courses that integrated project-based tasks and group discussions tailored to their skill level and interests. This research underscores the importance of providing diverse and flexible tasks in improving students' critical thinking skills, especially in STEM settings. research by Patel and O'Brien (2020) takes a deeper look at the influence of differentiated learning in engineering courses at a university in the United Kingdom. This study uses a mixed-method method to assess how adaptation to the speed and depth of the material can affect students' conceptual understanding and critical thinking skills. The results showed that students who took courses with differentiated learning approaches not only achieved higher academic outcomes but also showed improvements in the ability to apply knowledge in real-world situations. Both studies emphasize that the application of differentiated learning in the context of STEM education has a significant positive impact on the development of critical thinking skills, providing empirical evidence supporting the effectiveness of these methods. Therefore, this study aims to determine the influence of STEM-based differentiation learning to improve students' critical thinking skills in higher education.

Method

This research is a type of quantitative research with a meta-analysis approach. Meta-analysis research is a research approach that collects and analyzes previous research quantitatively with statistical methods to reach a conclusion (Tamur and Junadi, 2020); (Utomo et al., 2023; Putra et al., 2023; Ichsan et al., 2023). The research sample came from 12 national and international journals published in 2022-2024 indexed by SINTA, Web of Science and Scopus. The inclusion criteria are that the research must be relevant; research obtained from Mendeley, ScienceDirect, Google Scholar and ERIC databases, Research must be an experimental method; The study has complete data to calculate the effect size value and sample size > 25 students. Data analysis is quantitative statistical analysis with the help of JSAP software. Furthermore, the criteria for the effect size value in this study can be seen in Table 1.

Table1. Value Criteria Effect Size

Effect Size	**Kriteria**
0.0≤ES≤ 0.2	Low
0.2≤ES≤ 0.8	Medium
ES≥ 0.8	High

Sumber :(Zulkifli et al., 2022; Oktarina et al., 2021)

Result and Discussion

Based on the results of a search from the journal database, 124 studies were obtained, but only 12 studies met the inclusion criteria. Data that have met the inclusion criteria are calculated by the effect size value which can be seen in Table 2.

Tabel 2. Effect Size Value 12 Research

Journal Code	**Year**	**Veriabel**	**Education Level**	**Effect Size**
A1	2024	Critical Thinking	College	1.02
A2	2023	Critical Thinking	College	0.93

A3	2023	Critical Thinking	Colloge	0.87
A4	2023	Critical Thinking	College	1.26
A5	2024	Critical Thinking	College	2.08
A6	2024	Critical Thinking	Colloge	1.92
A7	2024	Critical Thinking	College	0.68
A8	2024	Critical Thinking	College	0.89
A9	2024	Critical Thinking	Colloge	0.99
A10	2022	Critical Thinking	College	0.68
A11	2022	Critical Thinking	College	0.52
A12	2024	Critical Thinking	Colloge	1.05
	Average effect size			**1.07**

Table 2, the results of the analysis of 12 studies showed the highest effect size value of 2.08 and the lowest of 0.52. According to the effect size criteria (Zulkifli et al., 2022) Of the 12 studies, nine (n=9) studies had high effect size values and three (n=3) had medium effect size criteria. Furthermore, the average effect size (d) = 1.07, there is a singnifiable effect of STEM-based differentiation learning on students' critical thinking skills in higher education. STEM-based differentiated learning allows lecturers to tailor activities and learning materials according to the individual needs of each student(Hariyadi et al., 2023). This approach helps in accommodating differences in learning pace, prior level of understanding, and diverse learning styles. Thus, students get the opportunity to explore STEM concepts in a more relevant and engaging way, which can directly improve their ability to critically process and analyze information (Ilma et al., 2023).

Furthermore, the use of project- and problem-oriented learning methods in differentiated STEM approaches often involves tasks that require higher-order thinking. These tasks force students to apply, analyze, and evaluate information rather than simply remembering facts (White, 2024). In this context, students are challenged to develop strong arguments, identify logical errors, and formulate innovative solutions to complex problems. This activity effectively fosters critical thinking skills because students must actively engage with the learning material and collaborate with their peers (Zainil et al., 2022). The use of this technology not only enriches the learning experience but also provides immediate feedback which is essential for the development of critical thinking skills. Through technology, students can repeat the material at their own level and gain a deeper understanding of difficult concepts (Qondias et al., 2022; Suwistika et al., 2024). STEM-based differentiation learning is important to ensure that learning objectives are achieved, especially in the context of developing critical thinking skills. These assessments should include a variety of methods, from standardized tests to student portfolios, to accurately portray the impact of learning (Rachmadtullah et al., 2023; Chukusol et al., 2024). The data from this assessment can be used to improve teaching approaches, adjust learning materials and activities, and continue to improve the effectiveness of STEM education in forming capable critical thinkers who are ready to face students' future challenges (Basak & Yucel, 2021).

Conclusion

From the results of the study, it can be concluded that STEM-based differentiation learning has a positive impact on improving students' critical thinking skills in higher education with a Hedge's (d) = 1.07 value in the high effect size category. The findings show that differentiation learning is effective to be applied to students in higher education to encourage their critical thinking skills in the learning process. STEM-based differential learning is not only relevant but also essential in contemporary higher education. This paves the way for the implementation of more innovative and responsive learning strategies that can significantly improve the quality of education and academic output of students. Therefore, the recommendation for higher education institutions is to continue to invest in the development and implementation of differentiated learning methods, with the main goal of optimizing the development of critical thinking skills among students.

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