Journal of Innovative Physics Teaching
Volume 2, Issue 2 December 2024, 102 -112
ISSN: 3021-8551 (Online)
Doi: https://doi.org/10.24036/jipt/vol2-iss2/53
https://jipt.ppj.unp.ac.id/index.php/jipt

The Effect of STEM-Based Interventions on Learning Outcomes in High School: A Meta-Analysis

Muhammad Aizri Fadillah, Atifah Hirahmah, Asrizal*, Usmeldi
Department of Physics Education, Universitas Negeri Padang, Padang, Indonesia.

Article Info

Article history:

Received June 27, 2024
Revised December 15, 2024
Accepted December 20, 2024

Keywords:

STEM education
Learning outcomes
High school
Meta-analysis
Effectiveness

ABSTRACT

While numerous studies have investigated the effectiveness of STEM (Science, Technology, Engineering, and Mathematics) education, findings remain fragmented, and variations in research designs, sample characteristics, and contexts of implementation pose challenges in drawing generalized conclusions. This study aimed to assess the efficacy of the STEM approach on student learning outcomes at the high school level through a meta-analysis. A total of 24 studies that met the inclusion criteria were analyzed from 14 papers that met the criteria. The meta-analysis results demonstrated that the STEM approach was significantly more effective than traditional learning methods, with an overall effect size value of $d = 1.71$, $Z = 7.45$, and a significance level of $P < 0.00001$. Although there was considerable heterogeneity among the effect sizes ($Q = 589.66$, $I^2 = 96\%$), the funnel plot demonstrated a symmetrical distribution of effect sizes, indicating minimal publication bias. The findings substantiate that STEM-based education can enhance student engagement, facilitate concept comprehension, and cultivate critical thinking abilities. The practical implications of this study include recommendations for education policymakers to design more effective STEM programs and for educators to adopt STEM-based teaching strategies. Various stakeholders must collaborate to guarantee this initiative's successful implementation and adequately prepare students for the global challenges they will encounter in the 21st century.

***Correspondence:**
Asrizal, Department of Physics Education, Universitas Negeri Padang, Padang, Indonesia.
email : asrizal@fmipa.unp.ac.id

INTRODUCTION

STEM, an acronym for Science, Technology, Engineering, and Mathematics, represents an interdisciplinary approach to education that integrates these disciplines to solve real-world problems. This concept has gained prominence in educational research and practice due to its potential to bridge the gap between theoretical knowledge and practical application (Al Hamad et al., 2024; Fadillah, Usmeldi, et al., 2024; Festiyed et al., 2024). The rapid advancements in technology and the increasing complexity of global challenges necessitate the development of skills and competencies that STEM education aims to foster. By emphasizing critical thinking, problem-solving, creativity, and collaboration, STEM education equips students with the tools necessary to thrive in the 21st century (Asrizal, Marjuni, et al., 2023; Fadillah & Sahyar, 2023; Yang & Ball, 2024).

STEM education is characterized by its emphasis on contextual and inquiry-based learning. Students engage in activities that simulate real-life scenarios, enabling them to apply theoretical concepts in practical settings. For instance, projects involving engineering design or scientific experimentation allow students to explore multidisciplinary approaches to problem-solving. This integrative method not only deepens students' understanding of subject matter but also enhances their ability to transfer knowledge across different contexts (Widya et al., 2019). Furthermore, STEM education encourages students to develop critical and analytical thinking, which is vital in addressing the multifaceted challenges of today's world.

The importance of STEM education extends beyond academic achievement; it is pivotal in preparing students for future careers in an increasingly technology-driven world. A report by Lalujan and Pranjol (2024) highlights that many professions now require a foundational understanding of STEM disciplines, coupled with the ability to apply this knowledge innovatively. Despite this, traditional education often compartmentalizes subjects, leading to fragmented learning experiences that do not fully harness the interconnectedness inherent in STEM fields. Consequently, the adoption of STEM education is increasingly seen as a critical step toward fostering a holistic and integrated learning environment that aligns with global workforce demands.

One of the core principles of STEM education is active learning, which promotes student engagement and participation. Through collaborative projects and team-based problem-solving tasks, students develop communication skills and learn to work effectively in diverse groups. These activities also enhance students' decision-making capabilities, self-confidence, and creativity, contributing to their overall personal and social development (Hinojo-Lucena et al., 2020). Moreover, the structured yet flexible nature of STEM programs encourages self-directed learning, empowering students to take ownership of their educational journey and adapt to new challenges independently. This pedagogical approach aligns with constructivist theories of learning, where students actively construct knowledge through meaningful experiences.

The implementation of STEM education varies across educational systems. Some institutions adopt a standalone STEM curriculum, while others integrate STEM principles into existing subjects. Emerging technologies, such as virtual labs, digital games, and simulation tools, have further expanded the possibilities for delivering STEM content effectively (Gumbi et al., 2024; Županec et al., 2022). For example, a meta-analysis by Wang et al. (2022) demonstrated that digital games could significantly enhance learning outcomes by making complex STEM concepts more accessible and engaging. These technological advancements not only improve the delivery of STEM content but also foster innovation and creativity among students, preparing them to leverage technology in solving real-world problems.

Despite the growing body of research on STEM education, the results of these studies are not always consistent. While numerous studies report positive outcomes, such as improved academic performance, motivation, and higher-order thinking skills (Saraç, 2018; Wahono et al., 2020), others highlight challenges and limitations. For instance, Judson (2014) noted variability in the effectiveness of STEM interventions across different contexts, and Bedar and Al-Shboul (2020) found no significant impact of STEM education on students' learning motivation. These discrepancies underscore the need for a more systematic examination of the factors influencing the success of STEM initiatives, including variations in implementation, student demographics, and the availability of resources.

This study seeks to address this gap by conducting a meta-analysis of recent research on the impact of STEM education on high school students' learning outcomes. Focusing on studies published between 2018 and 2023, this analysis aims to provide a comprehensive and nuanced understanding of how STEM approaches affect various aspects of student learning, including academic achievement, attitudes, and skills development. The objective of this research is to identify patterns, assess the overall effectiveness of STEM education, and determine key factors that contribute to its success or limitations in different contexts. Additionally, this study will investigate the influence of teaching strategies, technological integration, and curriculum design on the efficacy of STEM education.

The outcomes of this meta-analysis are expected to contribute to the ongoing discourse on optimizing STEM education. By identifying effective strategies and highlighting areas for improvement, this study aims to support the development of evidence-based practices that enhance the quality of education. Additionally, the findings will provide valuable guidance for integrating STEM principles into curricula, ensuring that students are well-prepared to navigate the complexities of a rapidly evolving global landscape. Ultimately, this research aspires to bridge existing gaps in the literature and offer actionable insights for educators, policymakers, and researchers, facilitating the advancement of STEM education to meet future societal and industrial needs.

METHODS

A meta-analysis is a statistical method that enables the simultaneous and quantitative evaluation of multiple existing studies. A meta-analysis aims to gain insight into the trends observed in quantitative findings by quantifying the effect sizes and measuring the differences between control and experimental groups (Fadillah, Asrizal, et al., 2024; Fadillah, Hirahmah, Puspita, et al., 2024; Gui et al., 2023). In this meta-analysis, the time frame for identifying pertinent articles was set between 2018 and 2023. The literature search was conducted through the Google Scholar database and assisted by the Publish or Perish (PoP) software program, as is customary in meta-analysis studies. This approach was employed by Antonio & Castro (2023) and Funa & Prudente (2021). The search employed Boolean operators, including "OR" and "AND," with the keywords utilized in the article search being "STEM" AND "experimental" AND "high school" AND ("learning outcomes" OR "achievement").

For studies to be eligible for inclusion in the meta-analysis, explicit inclusion and exclusion criteria were set to select relevant studies. In order for a study to be included in the meta-analysis, it had to meet the following criteria: (1) The research topic is STEM; (2) the research design is experimental, quasi-experimental, or mixed methods with pre-test/post-test; and (3) the research data is complete for meta-analysis. In contrast, the exclusion criteria were as follows: (1) Not focused on high school; (2) Not focused on STEM; (3) Published in conference proceedings; and (4) Did not have the required primary data, such as sample size, mean, and standard deviation. In the selection process, this study employed a flowchart derived from the PRISMA guidelines to enhance the quality of systematic reviews.

Following the screening process and the exclusion of ineligible literature, 14 relevant studies were included in the meta-analysis. Data analysis was performed using RevMan Manager 5.4, a specialized software tool for conducting meta-analyses. A random effects model was employed to calculate the overall effect size, accounting for variability across the included studies and enhancing the generalizability of the results. The interpretation of the effect size was guided by Cohen's d framework, wherein $d < 0.20$ $d < 0.20$ indicates no effect, $d \geq 0.20$ $d \geq 0.20$ represents a small effect, $d \geq 0.50$ $d \geq 0.50$ corresponds to a medium effect, and $d \geq 0.80$ $d \geq 0.80$ signifies a large effect (Cohen, 2013).

RESULTS AND DISCUSSION

Results

A total of 14 articles, encompassing 24 studies, were included in this meta-analysis to assess the impact of STEM-based approaches on high school students' learning outcomes. It is important to note that a single article may report multiple studies, as seen in the case of Lin et al. (2019), which included two separate studies. This approach allows researchers to explore different experimental conditions or variables within the same article, thereby contributing multiple datasets to the meta-analysis. Such a structure enriches the analysis by providing a broader range of evidence while ensuring that variations in STEM implementations are adequately captured. Consequently, the inclusion of 24 distinct studies from 14 articles offers a more comprehensive understanding of how STEM-based learning influences students' academic performance. These studies provided diverse perspectives, covering various learning contexts, sample sizes, and measures of learning outcomes.

Table 1. Articles Included in the Meta-Analysis

Author and Year	Me	Sde	Ne	Mc	SDc	Nc	NT
Abdurrahman et al. (2023)	82.42	5.61	31	75.28	7.74	36	67
Ab Kadir et al. (2021)	64.70	11.54	20	52.65	11.04	20	40
Alatas and Yakin (2021)	74.51	8.36	70	49.49	19.35	70	140
Ardianti et al. (2020)	81.50	5.10	27	60.59	5.17	27	54
Chen and Chang (2018)	76.20	23.33	42	41.00	14.26	42	84
Fadlina and Ritonga (2021)	76.37	12.20	292	36.93	12.25	292	584
Haryadi et al. (2021)	40.00	11.00	30	35.00	11.00	30	60
Lin et al. (2019) (Study 1)	76.62	17.62	78	69.83	17.66	71	149
Litn et al. (2019) (Study 2)	13.37	2.91	78	11.92	2.81	71	149
Listiana et al. (2019)	0.55	0.89	35	0.49	0.10	32	67
Samsudin et al. (2018) (Study 1)	14.64	2.38	28	5.64	2.44	28	56
Samsudin et al. (2018) (Study 2)	14.36	2.44	22	5.73	2.33	22	44
Samsudin et al. (2020)	3.53	0.25	50	3.24	0.32	50	100
Shahbazloo and Mirzaie (2023) (Study 1)	17.31	3.16	72	14.72	3.41	71	143
Shahbazloo and Mirzaie, (2023) (Study 2)	17.57	2.96	72	12.20	3.96	71	143
Shahbazloo and Mirzaie, (2023) (Study 3)	161.86	47.07	72	84.75	30.35	71	143
Shahbazloo and Mirzaie, (2023) (Study 4)	19.13	6.89	72	15.66	5.78	71	143
Shahbazloo and Mirzaie, (2023) (Study 5)	15.37	4.42	72	12.48	3.02	71	143
Shahbazloo and Mirzaie, (2023) (Study 6)	40.10	13.91	72	18.04	9.61	71	143
Shahbazloo and Mirzaie, (2023) (Study 7)	87.26	31.85	72	38.58	17.36	71	143
Simeon et al. (2022) (Study 1)	17.69	2.64	48	10.40	2.61	48	96
Simeon et al. (2022) (Study 2)	17.37	2.93	41	8.22	3.60	41	82
Sinurat et al. (2022) (Study 1)	82.81	9.99	32	36.72	8.09	32	64

Author and Year	Me	Sde	Ne	Mc	SDc	Nc	NT
Sinurat et al. (2022) (Study 2)	73.13	16.93	32	72.50	13.67	32	64

Note: mean of experimental group (Me), standard deviation of experimental group (SDe), number of experimental group (Ne), mean of control group (Mc), standard deviation of control group (SDc), number of control group (Nc), total study population (NT), not reported (NR)

Table 1 summarizes the key statistical data extracted from each study, including the mean scores and standard deviations for both experimental and control groups, the number of participants in each group, and the total sample size. This data forms the basis for the statistical analyses and interpretations presented in this section. The experimental group data (*Me*, *SDe*, *Ne*) represent students who received STEM-based instruction, while the control group data (*Mc*, *SDc*, *Nc*) correspond to those taught using traditional methods. The total population for each study is denoted as *NT*. The mean scores for the experimental groups (*Me*) demonstrate the impact of STEM interventions, which range from 0.55 (Listiana et al., 2019) to 161.86 (Shahbazloo & Mirzaie, 2023, Study 3). In comparison, the control group's mean scores (*Mc*) range from 0.49 to 84.75, showing consistently lower outcomes across the studies. The variation in standard deviations highlights the diversity of the studies. For instance, Chen and Chang (2018) exhibit a wide data spread in the experimental group (*SDe = 23.33*), while studies like Samsudin et al. (2020) demonstrate more consistent results with a lower standard deviation (*SDe = 0.25*). The sample sizes also vary significantly, from smaller cohorts of 40 participants (Ab Kadir et al., 2021) to larger groups such as 584 participants (Fadlina & Ritonga, 2021). This diversity reflects the broad applicability of STEM across different educational settings and provides a robust foundation for meta-analytic synthesis.

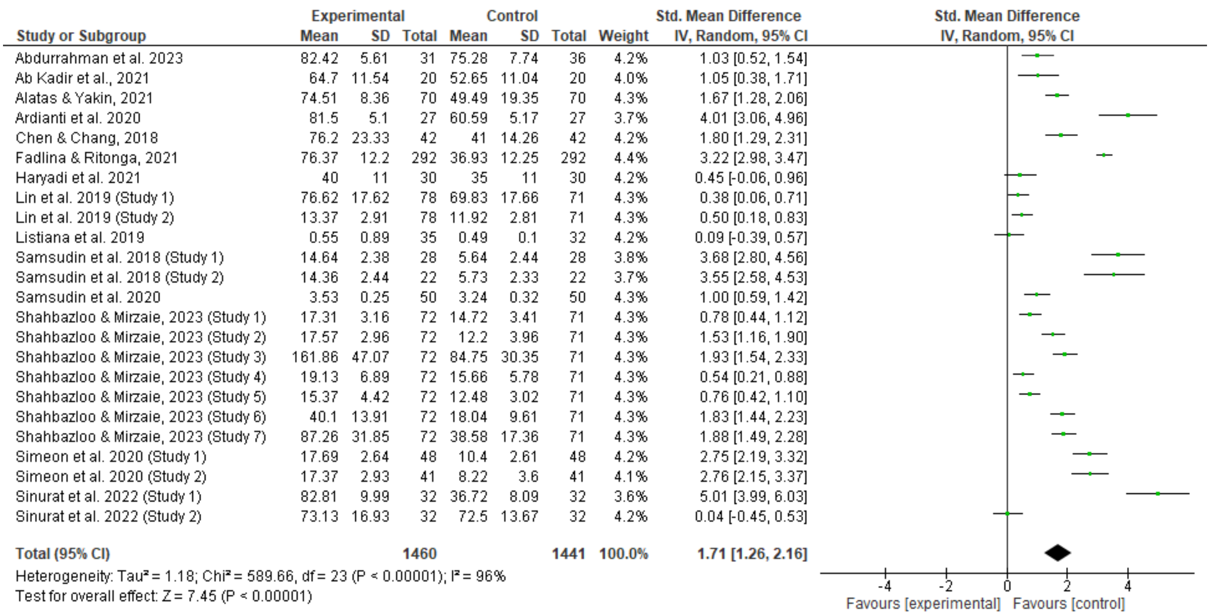

Figure 2. Forest Plot of Learning Outcomes in STEM

Figure 2 illustrates the forest plot, which aggregates the effect sizes from the 24 included studies, providing a visual summary of the impact of STEM-based instruction on learning outcomes. Each horizontal line represents the confidence interval for an individual study, with the central marker indicating the study's effect size. The diamond at the bottom represents the overall effect size ($d = 1.71$) synthesized from all studies. The majority of studies show positive effect sizes, with confidence intervals falling to the right of zero, indicating the superiority of STEM approaches over traditional methods. While individual effect sizes vary, studies like Shahbazloo and Mirzaie (2023, Study 6) (2023, Study 6) report exceptionally high impacts, whereas others, such as Simeon et al. (2022, Study 1), show more moderate effects. This variability may result from differences in study design, sample characteristics, or the specific STEM methods employed. The overall effect size (d = 1.71) is both statistically significant, with a Z value of 7.45 and a significance level of P <0.00001. The 95% confidence interval (1.26–2.16) further confirms the reliability of these findings. However, the analysis also reveals significant heterogeneity among the included studies (Q = 589.66, I^2 =96%), indicating considerable variability in effect sizes. This heterogeneity highlights the need for further exploration of contextual and methodological factors that may influence the efficacy of STEM interventions.

Funnel plots were employed to guarantee the precision of the findings and mitigate the potential for publication bias. Figure 3 depicts a funnel plot of the data analysis results. This plot examines the distribution of effect sizes in relation to their standard errors. A symmetrical distribution around the mean effect size suggests minimal publication bias in the included studies. Studies with larger sample sizes, such as those by Fadlina and Ritonga (2021), cluster near the top of the plot, reflecting greater precision and smaller standard errors. Conversely, studies with smaller sample sizes, like Ab Kadir et al. (2021), appear near the bottom, where standard errors are larger and confidence intervals are wider. The overall symmetry of the funnel plot indicates that the findings of this meta-analysis are not disproportionately influenced by selectively published studies, enhancing the reliability of the conclusions.

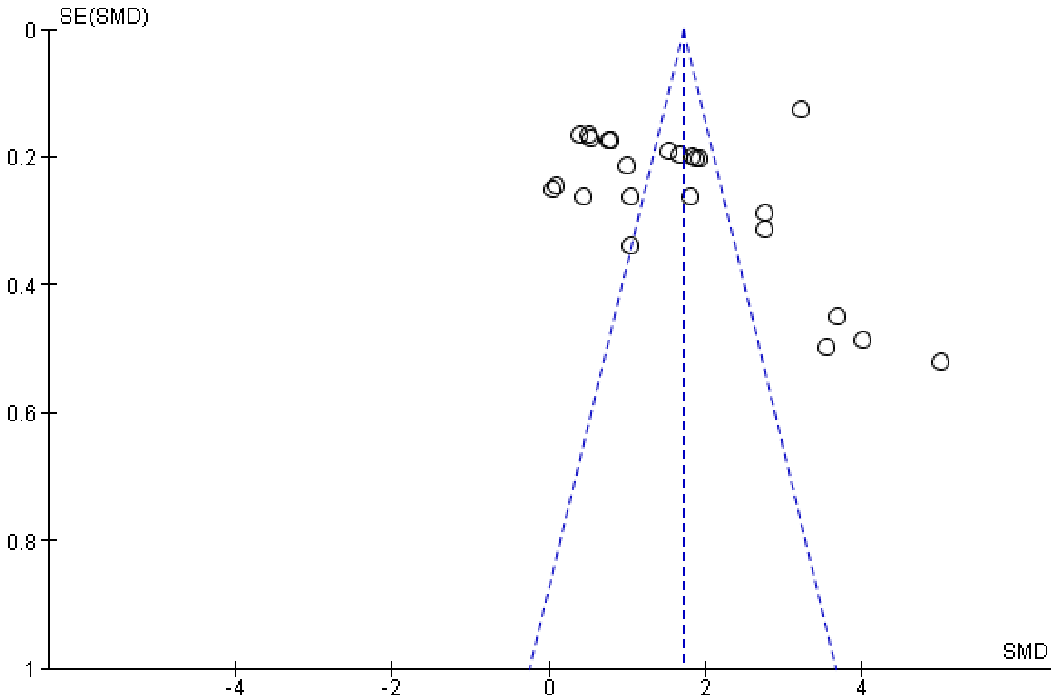

Figure 3. Funnel Plot of Learning Outcomes in STEM

The results of this meta-analysis demonstrate that the STEM approach has a profoundly positive and statistically significant impact on student learning outcomes at the senior high school level. The substantial overall effect size (d = 1.71) and its statistical significance (P < 0.00001) underscore the effectiveness of STEM in fostering deeper learning, critical thinking, and problem-solving skills. This strong evidence supports the integration of STEM methodologies into education curricula to address the evolving demands of the 21st century and to better prepare students for future academic and professional challenges. The findings also reveal that STEM approaches not only enhance students' academic performance but also contribute to increased engagement and motivation by promoting active and inquiry-based learning environments. By integrating real-world applications and interdisciplinary problem-solving, STEM methods make learning more relevant and meaningful, which could explain their significant impact on learning outcomes. Moreover, the heterogeneity among the studies (I^2 = 96%) highlights the importance of contextual factors such as the quality of instructional design, teacher expertise, available resources, and student characteristics in shaping the effectiveness of STEM interventions. Addressing these factors can further optimize the implementation and maximize the benefits of STEM education. Educational policymakers, school administrators, and teachers must, therefore, collaborate to ensure that STEM programs are well-supported, adequately resourced, and tailored to meet the diverse needs of learners.

Discussion

The findings of this meta-analysis offer compelling evidence that the STEM approach has a substantial, positive impact on student learning outcomes at the senior high school level. The high effect size value (d = 1.71) indicates that students who engage in STEM-based learning tend to demonstrate superior learning outcomes than those who follow traditional learning methods. This finding is consistent with previous research indicating that the STEM approach can enhance student engagement, facilitate concept comprehension, and cultivate critical thinking abilities. Nevertheless, the considerable heterogeneity among the effect sizes of the analyzed studies indicates a significant variation in the effectiveness of STEM implementation. This heterogeneity could be attributed to several factors, including differences in research design, the quality of STEM program implementation, sample characteristics, and the varying educational contexts present in each study. Consequently, it is imperative to conduct further moderator analysis to identify specific factors that influence the success of STEM implementation. For instance, the quality of teacher training, infrastructure support, and student engagement may be pivotal factors influencing the efficacy of STEM programs (Al Hamad et al., 2024; Fadillah, Hirahmah, Putri, et al., 2024; Yang & Ball, 2024).

One of the most significant findings of this meta-analysis is that the effectiveness of STEM programs in terms of student learning outcomes can vary considerably depending on how they are implemented. It suggests that the mere implementation of a STEM approach is insufficient; the success of such programs is contingent upon the quality of teacher training, the availability of resources, and the design and delivery of the curriculum. Further research is required to gain a deeper understanding of the key elements contributing to STEM approaches' effectiveness. For example, future studies could investigate the impact of continuous professional development for educators, the integration of technology in STEM education, and collaborative pedagogical strategies that engage students in hands-on activities (Anelfia & Mufit, 2023; Fadhiel & Mufit, 2024; Fitria & Asrizal, 2021; Mufit et al., 2020; Sandra et al., 2024; Usmeldi et al., 2017). Furthermore, the funnel plot, which displays a symmetrical distribution of effect sizes, provides evidence that the results of this meta-analysis are free from significant publication bias. Consequently, the inferences derived from these findings are deemed reliable and provide a precise representation of the impact of STEM on learning outcomes. Nevertheless, although publication bias is relatively limited, it cannot be entirely disregarded. Further research is necessary to ensure that negative studies or those showing non-significant results are also published and analyzed, thus providing a more comprehensive picture.

The practical implications of these findings are of significant relevance to those engaged in the field of education, including policymakers, educators, and researchers. The results provide a robust foundation for policymakers to develop and implement more efficacious STEM-based educational programs to enhance secondary education quality. Policies that facilitate the development and implementation of STEM curricula, including allocating sufficient resources and professional training for educators, can play a pivotal role in enhancing the efficacy of STEM programs (Al Hamad et al., 2024; Asrizal, Mardian, et al., 2022). For educators, the findings underscore the significance of integrating STEM methodologies into pedagogical approaches to enhance student engagement and learning outcomes. Teachers must receive training in STEM content and effective pedagogical techniques that can inspire and motivate students. Integrating technology, collaborative learning methodologies, and student-centered pedagogical approaches represents a potential avenue for enhancing the efficacy of STEM instruction (Asrizal, Yurnetti, et al., 2022; Gumbi et al., 2024).

Furthermore, these results allow researchers to investigate additional factors that may contribute to the success of STEM implementation, including contextual and individual variables. Future research should explore how factors such as students' socioeconomic background, family support, and school culture can influence learning outcomes in STEM contexts. Furthermore, longitudinal studies are required to assess the long-term impact of STEM education on students' academic and career development. This meta-analysis offers empirical evidence on the efficacy of STEM approaches and practical guidance for the future improvement of STEM education. It is crucial for enhancing the caliber of education and equipping young individuals with the skills to confront global challenges in the 21st century (Asrizal, N, et al., 2023; Widya et al., 2021). To attain this objective, fostering collaboration between policymakers, educators, researchers, and the broader community is essential. The successful implementation of the STEM approach will ensure that students are academically prepared and possess the requisite skills to thrive in an increasingly complex and high-tech world.

CONCLUSION

The results of this meta-analysis demonstrate that STEM-based approaches have a notable positive impact on student learning outcomes in senior high school. The overall effect size value of d = 1.71 indicates that these approaches are more effective than traditional learning methods. Notwithstanding the considerable heterogeneity among the effect sizes observed in the 24 studies analyzed, the results nonetheless provide compelling evidence of the benefits of STEM-based education. The findings are free from significant publication bias and have important practical implications for those engaged in the development of educational policy, as well as for educators and researchers. STEM approaches can enhance students' engagement, comprehension, and critical thinking abilities. Therefore, developing more effective educational programs is crucial by considering the factors that influence their successful implementation. It is essential to collaborate with policymakers, educators, researchers, and the wider community to ensure the successful implementation of STEM-based education and prepare students for the global challenges of the 21st century.

REFERENCES

Ab Kadir, W., Huda, W. N., Abdullah, N. S. Y., & Mustapha, I. R. (2021). The Effectiveness of Form Four STEM-Based Physics Interactive Laboratory (I-Lab) by Employing Isman Instructional Design Model. *Turkish Online Journal of Educational Technology-TOJET*, *20*(2), 140–145.

Abdurrahman, A., Maulina, H., Nurulsari, N., Sukamto, I., Umam, A. N., & Mulyana, K. M. (2023). Impacts of Integrating Engineering Design Process into STEM Makerspace on

Renewable Energy Unit to Foster Students' System Thinking Skills. *Heliyon*, *9*(4), 1-12.

Al Hamad, N. M., Ololade Elizabeth Adewusi, Chika Chioma Unachukwu, Blessing Osawaru, & Onyebuchi Nneamaka Chisom. (2024). A Review on The Innovative Approaches to STEM Education. *International Journal of Science and Research Archive*, *11*(1), 244–252.

Alatas, F., & Yakin, N. A. (2021). The Effect of Science, Technology, Engineering, and Mathematics (STEM) Learning on Students' Problem-Solving Skill. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *6*(1), 1.

Anelfia, S. C., & Mufit, F. (2023). Analysis of Needs Design of Cognitive Conflict-Based Teaching Materialis Integrated Augmented Reality on Material Sound Wave. *Journal of Innovative Physics Teaching*, *1*(2), 129–135.

Antonio, R. P., & Castro, R. R. (2023). Effectiveness of Virtual Simulations in Improving Secondary Students' Achievement in Physics: A Meta-Analysis. *International Journal of Instruction*, *16*(2), 533–556.

Ardianti, S., Sulisworo, D., Pramudya, Y., & Raharjo, W. (2020). The Impact of the Use of STEM Education Approach on the Blended Learning to Improve Student's Critical Thinking Skills. *Universal Journal of Educational Research*, *8*(3B), 24–32.

Asrizal, A., Mardian, V., Novitra, F., & Festiyed, F. (2022). Physics electronic teaching material-integrated STEM education to promote 21st-century skills. *Cypriot Journal of Educational Sciences*, *17*(8), 2899–2914.

Asrizal, A., Marjuni, M., Habibah, R., & Asiah, S. (2023). Meta-Analysis of the Effect of E Module on Students' Critical and Creative Thinking Skill in Science Learning. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 141–147.

Asrizal, A., N, A., Festiyed, F., Ashel, H., & Amnah, R. (2023). STEM-Integrated Physics Digital Teaching Material to Develop Conceptual Understanding and New Literacy of Students. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7), em2289.

Asrizal, A., Yurnetti, Y., & Usman, E. A. (2022). ICT Thematic Science Teaching Material with 5E Learning Cycle Model to Develop Students' 21st-Century Skills. *Jurnal Pendidikan IPA Indonesia*, *11*(1), 61–72.

Bedar, R. W. A.-H., & Al-Shboul, M. A. (2020). The Effect of Using STEAM Approach on Motivation Towards Learning Among High School Students in Jordan. *International Education Studies*, *13*(9), 48.

Chen, Y., & Chang, C.-C. (2018). The Impact of an Integrated Robotics STEM Course with a Sailboat Topic on High School Students' Perceptions of Integrative STEM, Interest, and Career Orientation. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(12).

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences*. Academic press.

Fadhiel, M. Al, & Mufit, F. (2024). Analysis of the Development of Augmented Reality Based Learning Media on High School Physics Material. *Journal of Innovative Physics Teaching*, *2*(1), 71–77.

Fadillah, M. A., Asrizal, A., Festiyed, F., & Usmeldi, U. (2024). The Effect of E-Modules on Physics Learning in Senior High School: A Meta-Analysis. *Indonesian Journal of Science and Mathematics Education*, *7*(3), 574–589.

Fadillah, M. A., Hirahmah, A., Puspita, S., Jannati, R. P., & Usmeldi, U. (2024). Pengaruh STEM terhadap Hasil Belajar Siswa dan Perbedaan Gender di Sekolah Menengah Atas: Sebuah Meta-analisis. *Jurnal Pendidikan Matematika Dan Sains*, *12*(2), 122–131.

Fadillah, M. A., Hirahmah, A., Putri, P. I., Andriyani, D. R., & Mufit, F. (2024). Exploring the Alignment of "Merdeka Belajar" with Nurcholish Madjid's Educational Philosophy: A Path to Inclusive and Independent Learning. *International Journal of Education, Information Technology, and Others*, *7*(3), 239–245.

Fadillah, M. A., & Sahyar, S. (2023). Development of Higher Order Thinking Skills (HOTS) Test Instruments on Parabolic and Circular Motion Materials in High Schools. *Berkala Ilmiah Pendidikan Fisika*, *11*(3), 329–338.

Fadillah, M. A., Usmeldi, U., Lufri, L., Mawardi, M., & Festiyed, F. (2024). Exploring User Perceptions: The Impact of ChatGPT on High School Students' Physics Understanding and Learning. *Advances in Mobile Learning Educational Research*, *4*(2), 1197–1207.

Fadlina, F., & Ritonga, S. (2021). The Implementation of STEM-Based Discovery Learning Model in Motion Systems Concept to Improve Learning Outcomes. *Asian Journal of Science Education*, *3*(2), 120–125.

Festiyed, F., Tanjung, Y. I., & Fadillah, M. A. (2024). ChatGPT in Science Education: A Visualization Analysis of Trends and Future Directions. *JOIV : International Journal on Informatics Visualization*, *8*(3–2), 1614–1624.

Fitria, Y., & Asrizal, A. (2021). Pengembangan Bahan Ajar Elektronik Energi dan Momentum Terintegrasi STEM Untuk Meningkatkan Hasil Belajar Siswa SMA. *Jurnal Pendidikan Fisika Dan Teknologi*, *7*(2), 119–130.

Funa, A. A., & Prudente, M. S. (2021). Effectiveness of Problem-Based Learning on Secondary Students' Achievement in Science: A Meta-Analysis. *International Journal of Instruction*, *14*(4), 69–84.

Gui, Y., Cai, Z., Yang, Y., Kong, L., Fan, X., & Tai, R. H. (2023). Effectiveness of Digital Educational Game and Game Design in STEM Learning: A Meta-Analytic Review. *International Journal of STEM Education*, *10*(1), 36.

Gumbi, N. M., Sibaya, D., & Chibisa, A. (2024). Exploring Pre-Service Teachers' Perspectives on the Integration of Digital Game-Based Learning for Sustainable STEM Education. *Sustainability*, *16*(3), 1314.

Haryadi, R., Situmorang, R., & Khaerudin, K. (2021). Enhancing Students' High-Order Thinking Skills through STEM-Blended Learning on Kepler's Law During Covid-19 Outbreak. *Jurnal Penelitian Dan Pembelajaran IPA*, *7*(2), 168.

Hinojo-Lucena, F.-J., Dúo-Terrón, P., Ramos Navas-Parejo, M., Rodríguez-Jiménez, C., & Moreno-Guerrero, A.-J. (2020). Scientific Performance and Mapping of the Term STEM in Education on the Web of Science. *Sustainability*, *12*(6), 2279.

Lalujan, J. D., & Pranjol, M. Z. I. (2024). Project-Based Learning as a Potential Decolonised Assessment Method in STEM Higher Education. *Trends in Higher Education*, *3*(1), 16–33.

Lin, Y.-T., Wang, M.-T., & Wu, C.-C. (2019). Design and Implementation of Interdisciplinary STEM Instruction: Teaching Programming by Computational Physics. *The Asia-Pacific Education Researcher*, *28*(1), 77–91.

Listiana, L., Abdurrahman, A., Suyatna, A., & Nuangchalerm, P. (2019). The Effect of Newtonian Dynamics STEM-Integrated Learning Strategy to Increase Scientific Literacy of Senior High School Students. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *8*(1), 43–52.

Mufit, F., Asrizal, A., & Puspitasari, R. (2020). Meta-Analysis of the Effect of Cognitive Conflict on Physics Learning. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *6*(2), 267–278.

Samsudin, M. A., Jamali, S. M., Md Zain, A. N., & Ale Ebrahim, N. (2020). The Effect of STEM

Project Based Learning on Self-Efficacy Among High-School Physics Students. *SSRN Electronic Journal*.

Samsudin, M. A., Zain, A. N. M., Jamali, S. M., & Ebrahim, N. A. (2018). Physics Achievement in STEM PjBL: A Gender Study. *The Asia Pacific Journal of Educators and Education*, *32*, 21–28.

Sandra, R., Asrizal, & Werina, W. (2024). Application of Differentiated Learning Through the Use of Interactive Multimedia to Promote Students' Scientific Literacy. *Journal of Innovative Physics Teaching*, *2*(1), 37–46.

Saraç, H. (2018). The Effect of Science, Technology, Engineering and Mathematics-STEM Educational Practices on Students' Learning Outcomes: A Meta-Analysis Study. *Turkish Online Journal of Educational Technology-TOJET*, *17*(2), 125–142.

Shahbazloo, F., & Abdullah Mirzaie, R. (2023). Investigating the Effect of 5E-Based STEM Education in Solar Energy Context on Creativity and Academic Achievement of Female Junior High School Students. *Thinking Skills and Creativity*, *49*, 101336.

Simeon, M. I., Samsudin, M. A., & Yakob, N. (2022). Effect of Design Thinking Approach on Students' Achievement in Some Selected Physics Concepts in the Context of STEM Learning. *International Journal of Technology and Design Education*, *32*(1), 185–212.

Sinurat, H. A. Y., Syaiful, S., & Muhammad, D. (2022). The Implementation of Integrated Project-Based Learning Science Technology Engineering Mathematics on Creative Thinking Skills and Student Cognitive Learning Outcomes in Dynamic Fluid. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *8*(1), 83–94.

Usmeldi, U., Amini, R., & Trisna, S. (2017). The Development of Research-Based Learning Model with Science, Environment, Technology, and Society Approaches to Improve Critical Thinking of Students. *Jurnal Pendidikan IPA Indonesia*, *6*(2), 318.

Wahono, B., Lin, P.-L., & Chang, C.-Y. (2020). Evidence of STEM Enactment Effectiveness in Asian Student Learning Outcomes. *International Journal of STEM Education*, *7*(1), 36.

Wang, L.-H., Chen, B., Hwang, G.-J., Guan, J.-Q., & Wang, Y.-Q. (2022). Effects of Digital Game-Based STEM Education on Students' Learning Achievement: A Meta-Analysis. *International Journal of STEM Education*, *9*(1), 26.

Widya, Rifandi, R., & Laila Rahmi, Y. (2019). STEM Education to Fulfil the 21st Century Demand: A Literature Review. *Journal of Physics: Conference Series*, *1317*(1), 012208.

Widya, W., Maielfi, D., Alfiyandri, A., & Hamidah, W. (2021). Creative Problem Solving-Based Electronic Module Integrated with 21st Century Skills. *Indonesian Journal of Science and Mathematics Education*, *4*(3), 333–342.

Yang, K.-L., & Ball, L. (2024). STEM Teacher Education Programs for Preservice and in-Service Secondary Mathematics Teachers: A Review Study. *Journal of Mathematics Teacher Education*, *27*(2), 185–207.

Županec, V., Radulović, B., & Lazarević, T. (2022). Instructional Efficiency of STEM Approach in Biology Teaching in Primary School in Serbia. *Sustainability*, *14*(24), 16416.