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STEM-integrated education: Assessment of the liquidity of training future specialists in the engineering and technical fields

Bakitzhan Kurbanbekov[1], Makpal Nurizinova[2], Sherzod Ramankulov[3], Yesim Yergobek[4], Madina Akeshova[5*]

[1,3,4]*Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkistan, Kazakhstan.*
[2]*Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk, Kazakhstan.*
[5]*International University of Tourism and Hospitality, Turkistan, Kazakhstan.*

Corresponding author: Madina Akeshova (*Email: madina_shakh@mail.ru*)

Abstract

This study aims to determine the impact of STEM education integration on students' cognitive activity, critical and creative thinking skills, and overall learning outcomes. Additionally, it seeks to identify the effectiveness and unique features of STEM integration in education. A systematic review of scientific literature was conducted using the PRISMA methodology. The Comprehensive Meta-Analysis 4.0 software was applied to ensure the accuracy and reliability of the review, allowing for an in-depth meta-analysis of research findings. This approach enabled the precise evaluation of the impact of STEM education integration on various educational indicators. The results confirm the high effectiveness of STEM integration in the educational process. The systematic review and meta-analysis conducted using Comprehensive Meta-Analysis 4.0 demonstrated that STEM education significantly enhances students' engagement, critical and creative thinking skills, and knowledge acquisition in science, technology, engineering, and mathematics. Furthermore, STEM approaches contribute to students' professional readiness by strengthening their problem-solving and analytical abilities. STEM integration plays a crucial role in modern education by fostering interdisciplinary connections between natural sciences, mathematics, and engineering. The application of Comprehensive Meta-Analysis 4.0 provided robust evidence that STEM-based teaching methods effectively improve students' cognitive and analytical abilities, making it a valuable and impactful approach in contemporary education. The findings of this study can be utilized to develop effective teaching strategies that incorporate STEM methodologies to enhance students' engagement, problem-solving skills, and academic performance. The integration of STEM approaches, validated through meta-analysis, serves as a strong foundation for future research on interdisciplinary learning and professional competence development.

Keywords: Engineering and technical field, Interdisciplinary communication, Meta-Analysis, STEM education, VR technology.

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1. Introduction

Engineering and technical disciplines are fundamental to modern technological advancements and economic growth. In an era dominated by rapid digitalization, artificial intelligence, energy efficiency, and innovative problem-solving approaches, the demand for well-trained specialists in these fields continues to rise. To address this demand, the integration of STEM (Science, Technology, Engineering, and Mathematics) methodologies into engineering education has become a crucial aspect of contemporary educational reform. STEM education promotes interdisciplinary learning by merging subject-specific knowledge with practical applications, thereby enhancing students' skills and professional readiness [1].

One of the key principles of STEM-based learning is the interdisciplinary approach, which encourages students to view scientific and technical subjects as interconnected rather than isolated disciplines [2]. This method significantly improves students' ability to apply theoretical knowledge in real-world scenarios, fostering their problem-solving skills, logical reasoning, and creativity. Furthermore, STEM education plays a pivotal role in bridging the gap between academic knowledge and industrial demands, equipping students with the necessary competencies to thrive in the global job market.

Despite the recognized benefits of STEM integration, several critical challenges remain unresolved, hindering its full implementation in engineering education. The first major challenge is the lack of well-defined methodological frameworks that effectively incorporate STEM-based approaches into engineering curricula. While various models exist, they often fail to address the complexity of engineering disciplines and their real-world applications [3]. Without a structured approach, educators may struggle to effectively integrate STEM principles into their teaching methods, limiting the overall impact on students' learning experiences.

Another challenge is the limited availability of comprehensive empirical studies that analyze the long-term effects of STEM education on students' professional competencies and research skills [4]. Although many studies highlight the short-term benefits of STEM learning, there is insufficient data on how these methodologies influence graduates' career readiness, innovation potential, and industry adaptability over extended periods. Addressing this gap requires extensive longitudinal research that evaluates the sustained impact of STEM-based education on students' academic and professional trajectories.

Additionally, the effective use of digital tools and interdisciplinary projects in STEM education remains an underexplored area. With the increasing integration of virtual laboratories, simulations, and AI-driven learning environments, educators and researchers must develop more efficient ways to incorporate these technologies into the teaching process. Leveraging Comprehensive Meta-Analysis 4.0, this study aims to evaluate the effectiveness of existing STEM integration strategies while identifying areas for improvement.

Given the complexity of modern engineering challenges, students must be equipped with a combination of theoretical knowledge, practical experience, and interdisciplinary problem-solving skills. The project-based learning approach has proven to be an effective method for integrating STEM into engineering education [5]. This methodology encourages students to work on real-world projects, simulating industrial environments and fostering collaboration among different disciplines. By implementing STEM-focused projects, students gain hands-on experience in applying scientific and technical concepts to practical situations, which enhances their ability to think critically and innovatively.

Furthermore, teacher training programs must be adapted to equip educators with the necessary skills to implement STEM-based teaching methods effectively. Without proper training, educators may struggle to incorporate interdisciplinary learning strategies into their lessons, reducing the potential impact of STEM integration [6]. Universities should establish dedicated STEM laboratories, providing students with access to cutting-edge technologies and experiential learning opportunities. Additionally, fostering collaborations with industries can help align academic programs with the evolving demands of the workforce, ensuring that students develop competencies that are directly applicable to their future careers.

On a macro level, governmental and institutional support play a crucial role in the successful implementation of STEM education in engineering disciplines. Investments in STEM programs, allocation of research grants, and international collaborations can significantly enhance the effectiveness of these educational strategies. Encouraging public-private partnerships can also facilitate the development of STEM initiatives that bridge the gap between academic institutions and industrial enterprises, fostering innovation and economic growth.

1.1. Research Steps

To address the challenges associated with STEM integration in engineering education and evaluate its effectiveness, this study follows a structured research methodology:

- A systematic analysis of existing STEM integration models in engineering education was conducted to identify key gaps and potential improvements. This step provided a foundational understanding of the best practices and limitations in STEM-based teaching.
- A meta-analysis was performed using Comprehensive Meta-Analysis 4.0 software to assess the effectiveness of STEM methodologies based on empirical data from previous studies. This tool allowed for a detailed statistical evaluation of how STEM integration influences students' academic performance, research competencies, and professional skills.
- Based on the findings from the literature review and meta-analysis, new STEM-integrated educational modules were designed. These modules incorporated project-based learning, interdisciplinary collaboration, and digital technologies to enhance the learning experience.
- The impact of these modules was assessed through qualitative and quantitative methods, measuring improvements in students' problem-solving abilities, critical thinking skills, and professional readiness.
- The study provides strategic recommendations for educators, institutions, and policymakers on how to improve STEM integration in engineering education. These recommendations emphasize the need for teacher training, digital tool integration, and industry collaboration to maximize the benefits of STEM education.

Incorporating STEM methodologies into engineering education is essential for preparing students to meet the demands of an increasingly technology-driven world. While the benefits of STEM integration are well-documented, challenges such as methodological gaps, lack of long-term studies, and limited use of digital tools must be addressed to maximize its effectiveness. By applying a systematic research approach, including a comprehensive meta-analysis, this study aims to provide valuable insights into how STEM education can be optimized to enhance students' academic and professional competencies. Implementing interdisciplinary, project-based, and technology-driven approaches will be crucial in shaping the next generation of engineering professionals.

2. Literature Review

Improving science, technology, engineering, and mathematics (STEM) education has become a global priority, especially in K-12 and higher education systems. In the United States, various educational reform initiatives emphasize the need for high-quality programs that integrate STEM subjects effectively. Researchers have demonstrated that STEM integration in physical science disciplines enhances student engagement and motivation, particularly when hands-on approaches are used [7]. STEM integration is not merely an instructional shift but a strategic curriculum transformation, designed to bridge the gap between theoretical knowledge and real-world applications [8, 9].

2.1. STEM Integration and Pedagogical Approaches

For K-12 education, interdisciplinary approaches to STEM have been widely recommended, with teachers being encouraged to integrate science, technology, engineering, and mathematics rather than teaching them as isolated subjects. In response to this need, various assessment tools have been developed to evaluate the effectiveness of integrated STEM instruction. These tools help measure the extent to which students engage with interdisciplinary STEM learning and how it influences their problem-solving skills.

A growing body of research highlights the role of technology-enhanced learning in STEM integration. For instance, the use of 3D printing has emerged as a promising tool for increasing student engagement in STEM disciplines. Studies indicate that students involved in 3D printing projects demonstrate higher levels of interest in STEM careers, particularly in engineering and applied sciences. While teacher involvement in 3D printing pedagogy was not a significant predictor of student interest, the level of STEM integration in classroom activities had a direct impact on students' motivation to pursue STEM-related careers [10-12].

2.2. Perceptions and Challenges in STEM Integration

Despite the growing recognition of STEM-based learning, its implementation in formal educational settings still faces challenges. A study conducted in Taiwan examined junior high school teachers' perceptions of STEM integration, focusing on their experiences in applying STEM methodologies in everyday teaching. The study revealed that while teachers acknowledge the benefits of STEM-integrated curricula, they often encounter structural and resource-based barriers, such as insufficient teaching materials, a lack of professional training, and limited interdisciplinary collaboration [13].

Furthermore, engineering design-based STEM integration has been identified as an effective approach, allowing students to apply scientific concepts through real-world problem-solving. Research findings suggest that students who engage in engineering-based STEM projects exhibit improved cognitive flexibility and interdisciplinary knowledge application. These findings reinforce the argument that STEM integration must go beyond traditional instructional techniques to promote deeper learning experiences [14].

2.3. The Role of Design Thinking and Inquiry-Based Learning in STEM

STEM integration is particularly crucial in addressing 21st-century learning challenges, where traditional siloed education models are insufficient to solve real-world problems. One effective method for enhancing STEM learning is design thinking, which encourages students to approach problems creatively, test multiple solutions, and engage in iterative learning processes [15]. A recent study analyzing the impact of design thinking in STEM education found that students engaged in active design projects showed higher problem-solving capabilities and teamwork skills compared to those taught through conventional methods.

Inquiry-based learning (IBL) has also been widely explored as a pedagogical approach to STEM education, particularly in the fields of physics and engineering. Recent research suggests that students who engage in inquiry-based STEM learning demonstrate higher retention rates, improved critical thinking skills, and enhanced creativity. These findings align with earlier research emphasizing that STEM education fosters a holistic approach to learning, where students not only acquire subject-specific knowledge but also develop transferable skills essential for technological and scientific innovation. [16].

2.4. STEM Integration and Its Impact on Critical Thinking

Critical and creative thinking skills are fundamental in addressing complex real-world challenges [17]. STEM-based learning environments provide students with opportunities to analyze problems from multiple perspectives, test hypotheses, and create innovative solutions [18]. Research has demonstrated that students engaged in STEM-integrated science education develop stronger logical reasoning abilities and problem-solving strategies than those in traditional learning settings.

Moreover, the integration of digital tools and virtual simulations has been shown to enhance students' engagement with STEM subjects. Virtual and augmented reality technologies, when incorporated into STEM curricula, provide immersive learning experiences that allow students to experiment with complex scientific concepts in simulated environments [19]. These technological advancements highlight the evolving nature of STEM education and its ability to adapt to modern learning needs.

2.5. Research Questions

This study aims to evaluate the effectiveness of STEM integration in education by addressing the following key research questions:

- How does STEM integration influence students' ability to connect different disciplines?
- What are the most effective tools and methodologies used for STEM integration?
- Does STEM integration enhance students' creative thinking and their ability to find innovative solutions?

By answering these questions, this research aims to deepen our understanding of the practical impact of STEM integration in the education system and contribute to its further refinement.

3. Research Methodology

3.1. Research Design

In the course of the study, the analysis of scientific papers was conducted according to specific criteria. Using the keywords "STEM integration," "STEM education," "interdisciplinary communication," and "pedagogical approach," scientific works from the last 10 years were considered. To enhance the statistical significance of the results, a meta-analysis of scientific papers was performed.

3.2. Data Collection and Selection Criteria

The process of analyzing scientific papers was developed in accordance with the declaration "PRISMA." A brief description of the journals selected for review is provided Table 1.

Table 1.
A brief description of the journals selected for review

Name of journals	Number of articles	By indexing
Journal of Science Education and Technology	2	Scopus
Journal of Turkish Science Education	1	ERIC
The Journal of Educational Research	2	Scopus
KnE Social Sciences	2	Google Scholar
European Journal of Science and Mathematics Education	1	ERIC
Journal of Baltic Science Education	2	Scopus
Solid State Technology	1	Scopus
Asia-Pacific Science Education	2	Scopus
International Journal of Instruction	2	Scopus

According to Table 1, the articles selected for analysis consist of four authoritative international journals. They include six journals indexed in the Scopus database, one journal in Google Scholar, and two journals indexed in ERIC. Thus, the selected articles from high-ranking journals can be considered of high quality. Research on the 15 selected articles will focus on analyzing problems based on the general characteristics and effectiveness of STEM integration.

3.3. Data Analysis Approach

The results of selected scientific papers allowed us to conduct a meta-analysis. The use of the meta-analysis method includes the purpose of studying the stages, selection criteria, data analysis, and stages of statistical analysis. The results of scientific papers were applied to calculate the measure of influence. In our analysis, the standardized average difference was determined by the size of the impact. The definition of the standardized mean difference is expressed in the following expression.

$$Standardized\ difference = \frac{\overline{X_1} - \overline{X_2}}{S} \quad (1)$$

The basic parameter required in determining the standard mean is the common standard deviation. The common standard deviation (S) results from the standard deviations of the two groups, with the basic formula shown in the expression.

$$S = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \quad (2)$$

3.4. Research Hypotheses

By entering data into the Comprehensive Meta-Analysis 4.0 software, we can obtain the results of the meta-analysis. Additionally, to simplify the calculation of forecast intervals when determining the data results, Microsoft Office Excel (Ms-Excel) version 2010 was used.

$H_{01:}$ The impact of STEM integration on students is not very significant.

$H_{02:}$ We can conclude that STEM integration is highly effective in education.

This study utilized the Comprehensive Meta-Analysis 4.0 program to evaluate the effectiveness of STEM integration, which has higher statistical accuracy than previous studies and allows for deeper data analysis. This method enables the calculation of the effect size between studies using a standardized mean difference (SMD) and analyzes the heterogeneity to improve the reliability of the results. While previous research has often been limited to qualitative analysis, this study aims to determine the actual statistical effectiveness of STEM integration using a quantitative meta-analysis method.

4. Research Results and Discussion

In this study, the result of the analysis of scientific papers on the effectiveness of the interdisciplinary connection of STEM integration in the education system is shown in Table 2.

Table 2.
The result of the analysis of scientific papers.

Meaning of the study	**Results obtained**	**Authors**	**Publishing name and publication period**
1	**2**	**3**	**4**
This study examines how design-based STEM integration curricula enhance student achievement in engineering, science, and mathematics by fostering interdisciplinary learning, problem-solving skills, and the practical application of theoretical concepts.	Demonstrated the impact of engineering integration on the natural sciences; STEM integration yielded positive results and highlighted achievements in the field of engineering.	Guzey, et al. [20]	Journal of Science Education and Technology, 2016
This study examines how STEM after-school programs influence student achievement and attitudes toward science, technology, engineering, and mathematics.	Using a multidisciplinary strategy of STEM integration, the approach and motivation of students toward STEM have been positively influenced by teacher development.	Ashford [21]	Doctoral dissertation, 2016
This study investigates the impact of STEM project-based learning (PBL) on students' achievement in four mathematics topics, emphasizing interdisciplinary and applied learning approaches.	Integration of STEM in education involves the assessment of students in mathematics within classes that combine science, technology, engineering, and project-based learning.	Han, et al. [22]	Journal of Turkish Science Education, 2016
This study examines the impact of STEM education on elementary student achievement in urban schools, focusing on its role in enhancing learning outcomes and problem-solving skills.	Using STEM integration in the study of mathematics by primary school students, the school rating was 68.37, indicating that STEM education was implemented.	Tolliver [23]	Doctoral dissertation, 2016

Meaning of the study	Results obtained	Authors	Publishing name and publication period
1	2	3	4
This study explores the impact of transferring to STEM-focused charter and magnet schools on student achievement, highlighting improvements in academic performance and STEM engagement.	Magnet schools focused on STEM integration had no effect, but charter schools focused on STEM integration had a positive effect.	Judson [24]	The Journal of Educational Research, 2014
This study focuses on the development of an ICARE-based geography e-module integrated with STEM and a spatial approach to enhance students' spatial thinking abilities.	With an integrated STEM product, learners were able to improve their spatial thinking by 92%.	Najifatuz, et al. [25]	KnE Social Sciences, 2023
This study examines the influence of knowledge and epistemological beliefs on chemistry teachers' STEM professional development and instructional practices, focusing on their roles in STEM-integrated classrooms.	The study showed that the students in the experimental group scored higher than those in the control group. Thus, it was found that STEM knowledge is strongly correlated with the STEM integration of learners.	Adebusuyi, et al. [26]	European Journal of Science and Mathematics Education, 2022
This study evaluates the effectiveness of an integrated STEM-PBL physics module in enhancing students' interest, sense-making, and effort in learning physics.	The STEM project-based learning module in teaching physics demonstrated that students significantly improved their thinking and interest skills, as well as their ability to think critically after the intervention.	Sulaiman, et al. [27]	Journal of Baltic Science Education, 2023
This study examines the effectiveness of an integrated STEM-PBL physics module in shaping students' beliefs about physics and learning physics, emphasizing its impact on engagement and conceptual understanding.	The intervention of the STEM-PBL physics module in physics has demonstrated positive learning effectiveness for the students. STEM integration is presented in the study of classical mechanics.	Rosales and Sulaiman [28]	Solid State Technology, 2020
This study reviews the impact of integrated STEM/STEAM education in South Korea, analyzing its effects on student learning, creativity, and interdisciplinary skill development.	Integrating knowledge from STEM classes demonstrates effectiveness in long-term memory and affective and cognitive learning.	Kang [29]	Asia-Pacific Science Education, 2019
This study explores the integration of project-based e-learning with STEAM as an innovative approach to enhancing students' understanding of ecological concepts through interdisciplinary and technology-driven learning.	As a result of mathematical and statistical analysis, the PjBeL STEAM learning system demonstrated an improvement in the learners' understanding of ecology.	Sigit, et al. [30]	International Journal of Instruction, 2022

As a result of the analysis of scientific papers, we conducted a meta-analysis by collecting data. The data that needs to be meta-analyzed are shown in Table 3.

Table 3.
List of data required for meta-analysis.

No.	Study name	Std diff means	Std error
1	**2**	**3**	**4**
1	Guzey, et al. [20]	0.187	0.065
2	Ashford [21]	0.18	0.071
3	Han, et al. [22]	0.214	0.089
4	Tolliver [23]	0.374	0.187
5	Judson [24]	0.429	0.089
6	Najifatuz, et al. [25]	2.7	2.7
7	Adebusuyi, et al. [26] 1	0.8	0.798
8	Adebusuyi, et al. [26] 2	1.2	0.726
9	Sulaiman, et al. [27] 1	1.8	0.1
10	Sulaiman, et al. [27] 2	1.2	0.11
11	Rosales and Sulaiman [28] 1	-5.5	0.034
12	Rosales and Sulaiman [28] 1	2.3	0.041
13	Kang [29] 1	0.8	0.102
14	Kang [29] 2	1.4	0.1
15	Sigit, et al. [30]	0.08	3.054

We will include the results in Comprehensive Meta-Analysis 4.0 and summarize the results of the meta-analysis. First, the initial conclusion is determined by the funnel plot. Through this diagram, we assess the deviation of the meta-analysis, which is illustrated in Figure 1.

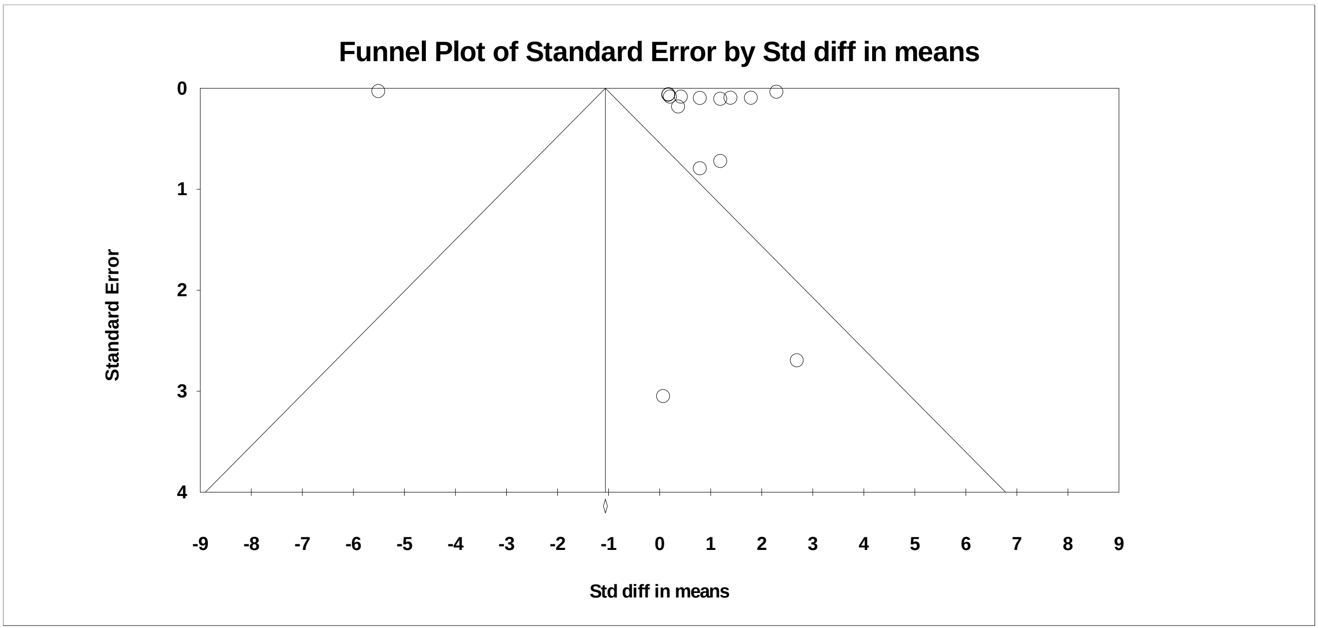

Figure 1.
The plot of the erected pit is used to determine the deviation in meta-analysis.

We can draw conclusions from a meta-analysis of the results of scientific papers using the Forest plot tool. Fifteen articles based on the Forest plot are presented graphically (Figure 2).

Model	Study name	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Guzey	0,187	0,065	0,004	0,060	0,314	2,877	0,004
	Ashford	0,180	0,071	0,005	0,041	0,319	2,535	0,011
	Han	0,214	0,089	0,008	0,040	0,388	2,404	0,016
	Tolliver	0,374	0,187	0,035	0,007	0,741	2,000	0,046
	Judson	0,429	0,089	0,008	0,255	0,603	4,820	0,000
	Zuhria et.al.	2,700	2,700	7,290	-2,592	7,992	1,000	0,317
	Adebusuyi	0,800	0,798	0,637	-0,764	2,364	1,003	0,316
	Adebusuyi	1,200	0,726	0,527	-0,223	2,623	1,653	0,098
	Sulaiman	1,800	0,100	0,010	1,604	1,996	18,000	0,000
	Sulaiman	1,200	0,110	0,012	0,984	1,416	10,909	0,000
	Rosales	-5,500	0,034	0,001	-5,567	-5,433	-161,765	0,000
	Rosales	2,300	0,041	0,002	2,220	2,380	56,098	0,000
	Kang (2019)	0,800	0,102	0,010	0,600	1,000	7,843	0,000
	Kang (2019)	1,400	0,100	0,010	1,204	1,596	14,000	0,000
	Sigit (2022)	0,080	3,054	9,327	-5,906	6,066	0,026	0,979
Fixed		-1,062	0,020	0,000	-1,101	-1,023	-53,729	0,000
Random		0,501	0,965	0,931	-1,391	2,392	0,519	0,604

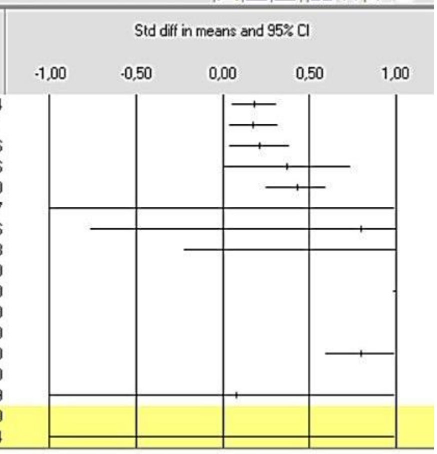

Figure 2.
Diagram and results of the forest plot in the meta-analysis.

Let's take a look at the conclusions that the Comprehensive Meta-Analysis 4.0 program has released. The analysis is based on fifteen studies. The impact size index (d) is the standardized difference between instruments.

As for the statistical model, a fixed-effect (singular) model was used for the analysis. The studies included in the analysis are from the same group and are similar to each other in all material respects. The results of this analysis are used only to draw conclusions for this group and are not generalized to other populations.

What is the overall impression size?

The overall effect size for these studies is -1.062, 95% confidence interval -1.101 to -1.023. The effect size in this population could decrease anywhere within this interval.

The Z-score tests the null hypothesis that the overall measure of impact is zero. Using the Alpha criterion Z-score of -53.729, $p < 0.001$. 0.050, we reject the null hypothesis and conclude that the effect size is not exactly zero in this population.

4.1. Q-test for Heterogeneity

The Q statistic provides a test of the null hypothesis that all studies in the analysis have a common mortality effect. If all studies have the same true measure of effect, the expected Q value is equal to the degrees of freedom (number of studies minus 1). Using the alpha criterion, the Q value with 14 degrees of freedom is 27180.926 and $p < 0.001$. 0.100. Therefore, we can reject the null hypothesis that the true effect size is the same in all these studies.

From the results provided by the Comprehensive Meta-Analysis 4.0 program, we can draw the following conclusion: the results of the meta-analysis indicate that STEM integration is highly effective in education.

After analyzing the scientific literature, we considered the need to apply the following aspects in the implementation of STEM integration into the education system:

1. STEM integration requires updating learning methods. This blurs the boundaries between subjects and gives students tasks to solve problems in the real world. For example, the use of the principles of mathematics and engineering in physics lessons helps students become accustomed to solving problems in a complex way.
2. The STEM methodology allows for the establishment of links between subjects in educational areas. By combining the subjects of Mathematics, Science, Engineering, and Technology, students are given the opportunity to connect theoretical knowledge with practice. This will help them develop critical thinking skills and find practical solutions.
3. In STEM subjects, the development of technical and digital skills is particularly important. Students master the skills of working with computer programs, data analysis tools, and other digital technologies, which makes them competitive in the modern labor market.

The effectiveness of the tools and methods used in STEM integration is as follows:

- Interactive technologies, such as VR glasses, provide students with the opportunity to visualize complex concepts and enhance their practical skills during the educational process.
- Project-based learning allows students to develop analytical thinking and problem-solving skills based on STEM education.
- Modular training programs allow you to learn different subjects holistically in STEM integration through this method. This contributes to the connection between theoretical knowledge and practical skills for students.

STEM integration enriches the educational process, prepares students according to the requirements of the modern world, and develops the skills necessary for them to become successful specialists in the future.

STEM integration makes important changes in the education system and contributes to the comprehensive development of students. This method provides students with the opportunity to apply theoretical knowledge in real life and prepares them in accordance with the new requirements of the future. The effectiveness of STEM lies in its aim to develop comprehensive abilities and enhance understanding of its role in the development of society.

In conclusion, it should be noted that STEM integration is highly effective in the education system.

We can assess the effectiveness of STEM integration in education by conducting a meta-analysis of scientific papers. In the results of the meta-analysis, we were able not only to determine the impact of STEM integration on the effectiveness of education but also to ensure that students develop analytical thinking skills and problem-solving abilities. By comparing these results with the scientific works of other researchers, we can demonstrate the benefits of STEM integration.

Moore, et al. [31] Explored the incorporation and integration of engineering within STEM education, emphasizing its role as a key component in K-12 STEM curricula. Their study provided a comprehensive review of existing literature on engineering integration in K-12 education and outlined fundamental principles for designing and assessing STEM-based instructional strategies.

Similarly, English [32] conducted research focused on STEM integration, highlighting the importance of balanced representation of all four STEM disciplines to enhance learning outcomes. The study emphasized that effective STEM integration not only strengthens disciplinary connections but also promotes interdisciplinary collaboration, leading to deeper engagement and improved educational outcomes. A promising approach for increasing student motivation and interest in STEM fields is the implementation of integrated STEM education [33]. This method equips learners with critical skills and knowledge essential for their future professional and societal roles [34]. Our research confirms that STEM integration positively influences students' academic performance, demonstrating its effectiveness as an educational strategy for fostering engagement and achievement.

5. Conclusion

STEM education plays a crucial role in modernizing the learning process and equipping students with essential technology and engineering skills. The integration of science, technology, engineering, and mathematics fosters critical thinking, creativity, and problem-solving abilities, which are essential for preparing students to tackle real-world challenges.

Additionally, STEM education enhances digital literacy, enabling learners to quickly adapt to emerging technologies and apply their knowledge to develop innovative solutions for society and the economy. The interdisciplinary nature of STEM learning also promotes collaborative teamwork, strengthening leadership and project-based learning skills.

Despite its many benefits, STEM integration faces several challenges. One limitation is the uneven implementation of STEM curricula across different educational institutions, which may lead to variations in student outcomes. Additionally, the lack of resources, qualified educators, and well-structured methodologies can hinder the effectiveness of STEM education. Another challenge is the rapid advancement of technology, which requires continuous curriculum updates to ensure that students acquire relevant and up-to-date knowledge.

Future research should focus on developing comprehensive STEM models that address the challenges of implementation and provide effective teaching strategies tailored to different educational settings. Additionally, longitudinal studies could examine the long-term impact of STEM education on students' career development and professional competencies. Further exploration is also needed to integrate emerging technologies such as artificial intelligence, virtual reality, and robotics into STEM learning environments to enhance engagement and effectiveness.

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