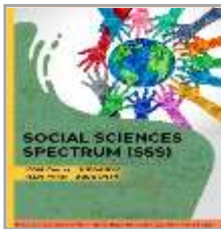

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The Effectiveness of STEM-Based Education in Promoting Positive Attitudes Towards Science Among Elementary School Students

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Abstract

This study assesses the transformative impact of STEM-based training on students' critical thinking skills and attitudes toward STEM disciplines, while also evaluating its effectiveness with conventional techniques. Using an effective Solomon Four-Group Experimental Design involving 8th grade students, the findings show that STEM-integrated education has significant benefits in developing analytical reasoning, problem solving, and deep interest in scientific research. Traditional teaching methods, on the other hand, produced only modest gains. The findings underscore STEM education's vital role in equipping children with the cognitive agility and innovative mindset required to thrive in an increasingly digitally driven world. By infusing STEM ideas into curricula, educators and governments may cultivate a next generation of innovative thinkers capable of managing global problems. This study advocates for innovative educational frameworks that seamlessly link theoretical understanding to real-world application, helping students to thrive in the ever-changing environment of the 21st century's knowledge economy.

Keywords: STEM-Based Education, Science attitudes, Middle school students, Experimental design, Environment.

Introduction

STEM approaches are well recognized for their transformative power in improving students 'attitudes toward science, enabling persistent engagement and transforming their perspectives of the topic. These strategies seek to strengthen eighth-grade students'' critical thinking skills, foster positive attitudes, and increase their retention of knowledge—all of which are in line with the expectations of a knowledge-driven economy, as highlighted by Osborne, Simon, and Collins (2023). According to Shah and Abbas (2023), retention, critical thinking skills, and a scientific mindset are the primary dependent variables, underscoring the significance of various educational perspectives. The adapted Watson-Glaser critical thinking appraisal, the Erkut and Marx (2005) attitude measuring scale, and delayed posttest results are produced by Friday's Institution in order to measure these variables and guarantee a thorough assessment of STEM's influence.

While STEM education has appealing theoretical basis, empirical evidence for its transformational impact on innovative attitudes and cognitive growth is fragmented and, at times, conflicting. For example, a study done in Pakistan found that early involvement in STEM-related disciplines improved pupils' critical thinking skills by 20% (ERIC, 2023). However, the trustworthiness of these results is compromised by a lack of extensive information on the approach of the research, its context, and size of the sample, making wide generalization difficult. Bridging this gap requires ongoing professional engagement and a dedicated effort to connect theatrical claims with actual implementation. To effectively apply STEM ideas into interesting and dynamic classrooms, teachers must have access to vital resources, strong support networks, and specialized training.

Blending STEM with PBL concepts appears to be a viable technique for reaching these objectives. Empirical evidence supports DeChambeau and Ramlo's (2017) claims that incorporating STEM into PBL allows for authentic, real-world training. This integration has been shown to improve pupil opinions toward learning, increase engagement, and reduce the dropout rate (Han et al, 2014). According to LaForce et al. (2017), problem-based learning enhances learning outcomes and boosts students' confidence in STEM subjects. However, there are significant obstacles to overcome in its implementation, such as a lack of finance, insufficient teacher training, and the need for curriculum that is suitable for the culture being targeted. Schools must also devise strategies to ensure equitable access to these services for all students, particularly those from low-income families.

Youngsters who participate in STEM programs gains significant life skills that go transcend academic performance, giving them the courage and trust they need to face obstacles in everyday life. STEM education encourages children to be engaged and assertive by fostering curiosity, removing negative stereotypes, and establishing good attitudes about study (Imran & Gunduz, 2023). To realize these advantages, equitable distribution of resources, culturally inclusive education, and competent instructors who can tailor STEM methods to the requirements of different pupils are required.

Students' opinions on science are influenced by a range of variables, such as their cultural and social upbringings, curricular structure, instructors influence, and gender differences. Because boys have more favorable opinions of science than girls, gender influences their educational and vocational preferences (Osborne et al., 2023). This disparity could be due to self-efficacy, cultural prejudices, or variations in passions. Targeted interventions, such as inclusive teaching approaches, mentoring services, and hands-on STEM activities, may assist to reduce these inequities, particularly in the formative years.

Students' attitudes toward science are significantly shaped by their teachers. The hands-on approach and inquiry-based learning significantly boost student engagement and enthusiasm when combined with positive reinforcement (Osborne et al., 2003). According to Fraser (1981), it is crucial to create environments for learning in classrooms that encourage constructive attitudes and active engagement through the behaviors of teachers and their instructional strategies. However, to guarantee that teachers are equipped to carry out successful PBL and STEM activities, these findings require regular investments in educational possibilities and teacher education.

Students' views about science are also influenced by the design of the curriculum. While real-world applications and inquiry-based learning pique students' interest and foster critical thinking, standard lecture-based teaching approaches usually fall shy (Bybee & McCrae, 2011; Osborne et al., 2003). More curiosity and active engagement are fostered in classrooms that prioritize collaboration, open communication, and teamwork. For these methods to be implemented on a larger scale, systemic issues including strict curricula and scare resources must be addresses.

Students' views toward science are also greatly influenced by cultural and socioeconomic variables. Students' attitudes toward science are significantly shaped by their teachers. The hands-on approach and inquiry-based learning significantly boost student engagement and enthusiasm when combined with positive reinforcement (Osborne et al., 2003). According to Fraser (1981), it is crucial to create environments for learning in classrooms that encourage constructive attitudes and active engagement through the behaviors of teachers and their instructional strategies.

Measuring attitudes about science is difficult due to its diverse character. Osborne et al. (2003) underline the importance of developing novel, context-sensitive tools capable of detecting modest attitudinal shifts. Tools such as the Fraser Test of Science-Related Attitudes serve an important role in giving accurate and nuanced assessments, allowing for a better understanding of students' changing scientific viewpoints. Standardized tests must account for cultural and contextual differences in order to be valid and reliable.

To fully realize STEM education's limitless potential, policymakers has to tackle a number of priorities. According to NSF (2010) and Osborne et al. (2003), these include promoting school-industry partnerships to inspire pupils to fill the skills disparity in workforce readiness; ensuring equitable availability of STEM opportunities and resources, particularly for underrepresented groups; and developing evolving, inquiry-based course that integrate STEM with real-world applications. STEM education may develop a more creative, inclusive, and efficient system that equips students to meet the needs of a modern, knowledge-based society by tackling these issues.

The goal of this study is to investigate how well a STEM-based instructional approach can improve students' attitudes towards science and critical thinking skills. It aims to fill in gaps in the literature and provide new insights to increase understanding of how STEM education can improve student achievement and prepare students for the knowledge-based economy.

Literature Review

According to Genc (2015), Petty and Cacioppo (1996) defined attitude as an unobservable tendency to conduct that is influence by either positive or negative attitudes toward and individual, object, or subject. In the discipline of science learning, this idea of attitudes has been used extensively, especially to understand how students interact with and interpret scientific ideas. Numerous studies on students' attitudes toward science have frequently indicated the prevalence of negative beliefs that restrict their engagement in academic inquiry and research (Arisory, 2007; Azizoglu & Cetin, 2009; Hacieminoglu, 2016). This topic has prompted much research into the factors that influences students' viewpoints, as well as methods of instruction aimed at modifying these attitudes and creating a pleasant and interactive learning environment.

Over the last three decades, experts in education have carried out extensive research on how students perceive science, identifying a number of influential factors such as gender disparities in academic achievement, teacher-pupil relationships, and classroom conditions. Research repeatedly shows a strong association between students' attitudes about science and their academic accomplishment, with more favorable perceptions being associated with greater achievement (Arisory, 2007; Freedom, 1997). Gender has emerged as a particularly important predictor, with various research looking at its impact, particularly on middle and high school pupils (Jones et al., 2000; Oakes, 1990; Simpson & Oliver, 1985, 1990; Catsambis, 1995; Greenfield, 1996).

The research on the impact the gender plays on pupil perceptions toward science yields mixed results. Several studies have found that middle school boys had more positive attitudes toward science than girls (Catsambis, 1995; Jones, Howe, and Rua, 2000; Piburn & Baker, 1993; Greenfield, 1996). Other studies, however, have revealed no significant gender disparities in students' attitudes of science (Dhindsa and Chung, 2003; Miller et al., 2002; Smist et al., 1994). Hacieminoglu et al. (2011) performed an extensive investigation of 2961 middle school students to evaluate the impact of parental training, gender, and grade level on their attitude toward science. Their findings demonstrated that the academic level had a substantial impact on students' acceptance of theories in science, enthusiasm for learning about STEM subjects, and career goals. In contrast, parenteral ethnic and academic achievement had little influence on students' perspectives, such as their ability to adopting a scientific approach.

More than 24,500 eighth-grade students participated in a study by Catsambis (1995b) that investigated gender disparities in science views. The findings showed that while female students were unable to participate in extracurricular scientific activities, male students were more likely to hold positive opinions about science. According to Hykle (1993) and Simpson and Oliver (1985b), males also showed a stronger preference for sciences, choosing science electives more frequently and frequently displaying a greater will to achieve in the subject. On the other hand, research by Archer and McDonald (1991) revealed that female students avoided taking more science classes because they had less faith in their academic skills.

Curiosity, several studies have shown that gender may have an impact on students'' perceptions of particular scientific fields, such as the biological or physical sciences. In general, boys are more interested in physical sciences, whereas girls are more interest in the sciences of biology (Schhibeci & Riley, 1986; Weinburgh, 1995). Girls were more interest in things like weather phenomena and animal communication, while boys were more interested in subjects like automobiles, daylight, electrical power, and new energy sources, according to Jones, Howe, and Rua (2000). This collection of studies focuses on the impact of gender on the specific scientific fields in which students are most interested.

One of the most noteworthy findings from the literature is the reciprocal connection between attitude and scientific progress. A positive mindset toward science are not only linked to higher scores in school, yet they are also regarded to be a strong predictor of future achievement in the field. According to Schibeci and Riley (1986), optimistic attitudes contribute to more success, not the opposite. Furthermore, research has demonstrated that teaching strategies, goal orientations, and self-efficacy all play important factors in how well children perform academically in sciences (Weinburgh, 1995).

According to current studies, negative opinions toward science are closely related to a growing disinterest for the discipline, particularly among female students. Attitudes are multifaceted and involve behavioral, emotional, and cognitive components that interact to shape student’s perspectives (Adi Widodo et al., 2018; Purnami et al., 2018). Attitudes are formed by mental experiences and associations with subject matter, and they are affected by psychological, cognitive, and behavioral aspects.

Scientific education has traditionally aimed to create positive attitudes towards science, regardless of individual characteristics (Arisoy, 2007; Azizoglu & Cetin, 2009). Osborne (2003) defines attitudes as people’s feelings, beliefs, and ideas about science and its role in society. Newhouse (1992) asserts that attitude is a wide concept that includes both positive and negative reactions to situations, objective, or subjects. Six elements of mindsets towards science were identified by Klopfer (1976): acceptance of scientific curiosity as a way of thinking, favorable views toward science and its practitioners, flexibility, enthusiasm for learning experiences, and a desire to work in research.

The significant influence of attitude on conduct was underlined by Newhouse (1990), who pointed out that attitudes are influenced by a variety of factors, including life events, education, and personal decisions. Also, studies on the science learning environment indicate that setting of science instruction has a big impact on student’ attitudes (Riah & Fraser, 1997; Aldridge & Fraser, 2000). Preference, admiration, and commitment to scientific pursuits are examples of emotional behaviors that are influenced by attitudes.

Since the careers students choose in STEM disciplines are influenced by their positive STEM attitudes, an increasing amount of research emphasizes the significance of fostering these attitudes in elementary school (Unfried et al., 2015). Students’’ propensity to react to the contextual influences around them, such as the way concepts are presented, the learning material, and psychological elements like language and symbols, is what Ardies et al. (2014) characterize as attitude. Cognitive abilities affective, and natural tendencies—the three basic elements of attitude—interact with one another, highlighting the significance of a comprehensive strategy for promoting favorable attitudes toward science.

Although attitude’s cognitive component frequently predominates, it’s equally critical to acknowledge the impact of its emotive and behavioral aspects (Soh, Arsada, & Osman, 2010). Because students who have a good attitude toward research are more likely to appreciate the value of scientific understanding in their future careers, Noorhidawati et al. (2015) claim that the cognitive part of attitude can influence students’ career choices (Zain, 2010). Students’ interest in STEM occupations is greatly influenced by their impressions of STEM disciplines, according to the Social Cognitive Career Theory (SCCT), and having a positive attitude is essential for continuing such careers (Lent et al., 2000).

Developing a positive attitude toward science, particularly STEM topics, is critical for students’ academic pathways and future professional options. According to research, beginnings with STEM attitude in the classroom have a significant impact on students’ goals to pursue STEM employment (Karahan & Roehrig, 2016), as well as positive attitudes toward science enhance engagement in scientific investigation and study (Pitafi & Farooq, 2012). At the end of the day, promoting favorable attitudes toward science and STEM education is critical to developing scientifically literate individuals who can enhance society’s technological and scientific skills and contribute to the labor market.

Methodology

This study employed a true experimental design (Campbell & Stanley, 1963), resulting in is ideally suited for examining casual correlations by randomly assigning individuals to different groups. In this approach, two groups, denoted O1 and O3, experimental and control pretest gropes respectively, are assessed before the test. Following that, four distinct groups develop: two experimental (E1 and E2) and two control (C1 and C2). The STEM-based instruction regimen is implemented in the experimental groups, whilst the control groups receive their education conventionally. After a period of six weeks, all four groups take a posttest to assess the improvement in their ability to think critically and attitudes towards sciences. The study involves 184 eighth-grade teenagers, who were randomly assigned to four groups of 46 each. These students were recruited from a public high school. Before starting data collection, both the eighth-grade class instructors and the school principal provided written consent, assuring full conformity with ethical norms.

Table 1: *The Solomon Four-Group Design*

		Pretest	Treatment	Posttest
R	Group 1	O1	X	O2
R	Group 2	O3		O4
R	Group 3		X	O5
R	Group 4			O6

Note: R: Randomization, X: Treatment, O: Outcomes.

S-STEM Survey

A closed-ended questionnaire (the S-STEM survey) was used to gauge students' attitudes towards STEM. North Carolina State University's Friday Institute (2012) created a five point Likert scale to assess students' attitudes about science, mathematics, engineering, and technology.

S-STEM Survey Development and Validation

Constructs were developed using Erkut and Marx (2005), Langdon et al. (2011), and the Bureau of Labor Statistics (2010-2011).

A pilot study was carried out with 109 students to assess reliability and validity.

Loadings greater than 0.40 determined the construct's relevance.

Content validity is determined using Lawshe's content validity ratio (CVR).

Final tests: The survey was revised based on the replies of 9,081 middle/high school students and 799 primary pupils. Subsequent testing of this questionnaire's dependability revealed the following results.

Table 2: *Cronback Alpha values for STEM Survey for Middle School Students*

Construct	No. of Items	Cronback Alpha
Math	8	0.90
Science	9	0.89
Engineering and Technology	9	0.90
Critical Thinking Skill 21st-century learning	11	0.92

Note: this indicates that higher levels of validity are discovered for the survey. The poll was used in the current investigation. The goal was to comprehend the eighth-grader perspectives on STEM courses.

CFA Measurement Model Outcomes

To assess the latent structure of the suggested conceptual model, the researcher performed a Confirmatory Factor Analysis (CFA) on the sample data (n = 119) with AMOS 24.0 (Arbuckle, 2012). The maximum likelihood estimate approach was used in this investigation. To create the first-order CFA, all latent components were estimated as first-order factors that were interconnected. The analysis exhibited good reliability qualities, with the Average Variance Extracted (AVE) for all constructs exceeding the recommended standards of 0.50 and 0.70 (Hair et al., 2010). This demonstrates the constructions' reliability. The first-order measurement model was examined and validated. Convergent validity was determined with a factor loading threshold of 0.70 and a statistical significance level of $P<.01$. Previous study indicates that factor loadings above 0.70 are desirable, whereas loadings above 0.60 are acceptable. The results reveal that all first-order factor scales have appropriate reliability and validity, indicating that the measurement model is robust.

Results and Discussion

Group 1 (Intervention): Comparison of Students' Attitude towards (Overall) Mathematics, Science, Engineering and Technology, and Critical Thinking.

Paired-Samples t-test:

The posttest scores (M = 160) showed a significant improvement over the test results (M = 142), with a mean difference of 18.13 (SE = 2.21). The paired-samples t-test yielded statistically significant results ($t(45) = 8.02$, $p < 0.05$).

Table 3: *Descriptive Statistics for Pretest and Posttest Scores*

Test	Mean	(SD)	(N)	(SE)
Pretest	142	15.0	46	2.21
Posttest	160	4.07	46	0.601

Shapiro-Wilk Normalcy Test

The assumption of normalcy was met for this group ($W = 0.985$, $p = 0.799$), supporting the use of parametric tests such as the t-test.

Test of Wilcoxon Signed Rank

The STEM approach considerably improved teenagers' performance, as indicated by this non-parametric test ($V = 1035.5$, $p < 0.05$).

Conclusion

The intervention greatly enhanced students' critical thinking skills and attitudes toward STEM, demonstrating the effectiveness of the STEM-based instruction.

Group 2 (Traditional): Pre and Post Comparison of Students' Attitude (Overall) Mathematics, Science, Engineering and Technology, and Critical Thinking.

Students' mean scores from the pretest and posttest were compared using a parried-samples t-test. Table 4 presents descriptive statistics that demonstrate a substantial difference (mean difference of -4.07, SE = 1.02) between the pretest mean score (M = 140, SD = 7.95) and the posttest mean score (M = 136, SD =6.91).

Table 4: *Descriptive Statistics for Pretest and Posttest Scores*

Test	Mean	(SD)	(N)	(SE)
Pretest	140	7.95	46	1.17
Posttest	136	6.91	46	1.02

Shapiro-Wilk Normalcy Test

The test revealed a significant deviation from normalcy (W = 0.922, p = 0.0042), implying that the data did not fully fulfill the paired-samples t-test's normality assumption.

Paired-Samples t-test:

Compared to the intervention group, the conventional group exhibited no significant improvement. The mean score of pretest (M = 140) was slightly higher than the posttest mean (M = 136), with a mean difference of -4.07 (SE = 1.02), but no significant difference was discovered (t (45) = -3.71, p = 0.00056).

Test of Wilcoxon Signed Rank

Similarly, the Wilcoxon test revealed no significant change in scores (V = 106, p =0.00012), confirming the absence of improvement.

Conclusion

The typical teaching style produced no substantial increase in the achievement of pupils or attitudes toward STEM. This shows that the STEM-based pedagogical method was more successful.

Group 3 and Group 4: Comparison of Posttest Overall Mathematics, Science, Engineering and Technology and in Critical Thinking 21st Century Learning – Traditional versus Intervention

Independent-Samples t-test:

The posttest scores of the traditional (M = 136) and intervention groups (M = 164) differed significantly in favor of the interventional group. The intervention group has a significantly higher mean (t (57.001) = 15.8, p < 0.0001) with a 95% confidence interval of [24.41, 31.50].

Table 5: *Descriptive Statistics for Pretest and Posttest Scores*

Test	Mean	(SD)	(N)	(SE)
Pretest	136	11.3	46	1.66
Posttest	164	4.15	46	0.612

F-Test for Variance Equality

The intervention group had considerably lower variability in scores compared to the control group ($F = 0.1358$, $p < 0.05$).

T-Test for Welch Two-Sample

Given the variability of the difference, the Welch t-test was done, which revealed a significant variance in means, demonstrating that the treatment group outperformed the traditional group.

Conclusion

When contrasted to traditional teaching techniques, STEM-based training was much more effective at improving students' overall performance.

A comparison of Results:

Effectiveness of Treatment:

The STEM-based instructional strategy has a constant positive impact, as seen by the results of Group 1 (Intervention) and Group 3 (Posttest Comparison). Conversely, Group 2 (Traditional) exhibited no significant change, indicating that the intervention was effective.

Statistical Evidence:

The STEM treatment resulted in significant improvements as shown through both parametric (paired-samples t-test) and nonparametric (Wilcoxon signed-rank test) analyses. The consistent findings obtained from parametric and nonparametric tests support the traditional group's lack of improvement.

Variance and Consistency:

The intervention group had not only higher scores, but also more consistent outcomes, as evidenced by the smaller variation when compared to the conventional group.

Discussion

The result for Group 1 (Intervention) reveal that the STEM-based intervention significantly improved students' attitudes toward Mathematics, Science, Engineering & Technology, and Critical Thinking. The parried-samples t-test showed a significant increase in mean scores from the pretest ($M = 142$, $SD = 15.0$) to the posttest ($M = 160$, $SD = 4.07$), with a mean difference of 18.13 ($t(45) = 8.02$, $p < 0.05$). The Wilcoxon signed rank test supported this finding ($V = 1035.5$, $p < 0.05$), showing a significant improvement in student performance. These data indicate that a STEM-based approach significantly improved student's attitudes about the courses.

In contrast, Group 2 (Traditional) had a statistically significant reduction in mean scores from the pretest ($M = 140$, $SD = 7.95$) to the posttest ($M = 136$, $SD = 6.91$), with a mean difference of -4.07 ($t(45) = -3.71$, $p = 0.00056$). The Wilcoxon signed rank test verified this finding ($V = 106$, $p = 0.00012$), demonstrating a deterioration in students' opinions about traditional teaching approaches. In Group 3 and 4, the Intervention group had a significantly higher mean score ($M = 164$, SD 4.15) than the Conventional group ($M = 136$, $SD = 11.3$), with a mean difference of approximately 28.96 points, as confirmed by the Welch Two-Sample t-test ($t(57.001) = 15.8$, $p < 0.0001$). These findings demonstrate the STEM approach's superiority in enhancing students' mindsets and critical thinking skills.

Implications

The STEM-based instructional approach improves the attitudes of pupils towards Mathematics, Science, Engineering & Technology, and Critical Thinking. The intervention group showed substantial rise in mean scores from 142 ($SD = 15.0$) to 160 ($SD = 4.07$) ($t(45) = 8.02$, $p < 0.05$). In contrast, scores in the traditional instruction group fell from 140 ($SD = 7.95$) to 136 ($SD = 6.91$) ($t(45) = -3.71$, $p = 0.00056$), highlighting the limitations of traditional techniques. These findings suggest that STEM-focused teaching practices could be vital for increasing both academic achievement and the ability of pupils to think critically, equipping them for future difficulties in a technologically driven environment.

Conclusion

This study found that STEM-based training significantly improves eighth-grade students' critical thinking skills across all domains, including inductive thinking, interpreting, argument, and assumption, as compared to traditional techniques. The findings, based on a strong Solomon Four-Group design, reveal that STEM-based training promotes considerable a long-term cognitive advantages, along with significant gains in subsequent studies testing as well as retention posttest scores. Furthermore, the intervention had a favorable impact on students' attitudes toward mathematics, science, engineering & technology, and critical thinking, as indicated by a significant increase in posttest scores in the intervention group compared to pretest scores. The study implies that broader, more diverse samples, as well as longitudinal research, may enhance generalizability and provide more insight into long-term consequences. Based on the results of the study, it is recommended that STEM be embedded across disciplines, educators be empowered with specialized training, hands-on and collaborative learning models be adopted, advanced STEM facilities be invested in, Home-School-Community linkages be strengthened, and dynamic assessment practices be implemented to ensure STEM education' sustainability and continued success.

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