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Effectiveness of STEM Approach on Enhancing Critical Thinking Skill of Elementary School Students

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Abstract

The ground breaking study aims to further a fundamental educational objective: fostering in young people the critical thinking skills necessary to create a future of knowledgeable, creative, and civically active individuals who will drive both societal advancement and country prosperity. Through an exploration of the transformative potential of STEM (science, technology, engineering, and mathematics) approach, this study advances our knowledge of how focused instruction can improve students' cognitive skills. 184 young learners in the eighth grade from public sector schools were carefully selected at random and put through a demanding Solomon Four-Group design. STEM-based approach instructions versus traditional teaching methods were compared for their relative effects using a 2x2 factorial methodology. The results show that a STEM-based approach is incredibly effective at fostering critical thinking skills. The critical thinking scores of the experimental groups showed a notable improvements from the pretest ($M = 45.32$, $SD = 4.15$) to the posttest ($M = 63.47$, $SD = 5.03$), and the retention posttest scores showed a sustained improvement ($M = 61.89$, $SD = 4.72$). Conversely, the control groups advanced very little (pretest: $M = 4.87$, SD 4.23). Critical thinking skills are effectively advanced by the STEM method, as seen by <the significant interaction effect ($F(1, 180) = 36.53$, $p < 0.05$) and high effect

size (Cohen's $d = 1.52$). Significant pretest ($F(1,180) = 40.28$, $p < 0.05$) and treatment effects ($F(1,180) = 576.21$, $p < 0.05$) were shown by further analysis, confirming the influence of STEM pedagogy on cognitive development. These results highlight STEM approach as a potent catalyst for developing elementary school children' critical thinking skills and laying the groundwork for a workforce prepared to take on challenging global in the future. This study emphasizes how educational systems must embrace innovative pedagogies that go beyond conventional content delivery and provide students with dynamic opportunities to think critically, analyze, and create.
Keywords: Solomon Four-Group Design, STEM approach, elementary school students, critical thinking skills

1 Introduction

STEM-based approach appears to be here to stay, yet educational trends can change over time. The word used to characterize this integration is STEM. Students need to be able to think critically in order to assess, analyze, and generate information in the twenty-first century. The STEM approach integrates multidisciplinary teaching and learning techniques that promote problem-solving and critical thinking skills, claims Bybee (2010). Recent years have seen a global push to include STEM-based instruction in curricula to better prepare students for the problems of the future (National Research Council, 2011).

The implementation and results of STEM education are greatly impacted by cultural factors, educational regulations, and teacher preparation. The ability to think critically is essential for addressing difficult problems and making decisions (National Research Council, 2012). Bybee (2010) asserts that traditional educational approaches are less successful in developing higher-order cognitive skills because of their low levels of involvement and practical application. The STEM approach integrates several fields and provides an intensive, multidisciplinary learning experience (Sanders, 2009). Honey, Pearson, & Schweingruber (2014) suggest that this approach enhances critical thinking skills more effectively than traditional methods due to its emphasis on group learning, experiential learning, and real-world problem-solving.

There is still uncertainty regarding the advantages of STEM-based education, particularly in elementary schools, and in-depth evaluations are advised to determine how they affect critical thinking. The purpose of this study is to close this knowledge gap by comparing how STEM-based

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approach and traditional teaching methods affect elementary school pupils' critical thinking skills. In order to investigate both the immediate and long-term impacts of the instructional approaches, this study will employ retention posttests in a Solomon Four-Group design (Campbell & Stanley, 1963). The study's findings will provide valuable insights into how STEM approaches promote critical thinking as more effective teaching methods are created. Today's technologically evolved world requires a STEM-based approach to foster innovation and economic success. Countries may compete in global markets by prioritizing STEM education since it produces critical thinkers and problems solvers (UNESCO, 2017). Yet, a variety of problems with Pakistan's educational system, such as outdated training, a lack of funding, and insufficient teacher preparation, might make it challenging to successfully implement STEM education (Khalid & Khan, 2021).

Critical thinking skills are necessary for both academic achievement and informed citizenship (Paul & Elder, 2008). Critical thinking aids in situational analysis, decision-making, and the formulation of personal as well as professional objectives, claims Facione (2011). Bybee (2010) highlights that a crucial element of STEM education is inquiry-based activities that enhance students' problem-solving skills. The study evaluates the effectiveness of STEM-based instruction in enhancing critical thinking skills in elementary school students, highlighting the need for more scientific data to evaluate its impact on this increasingly popular educational approach (Honey, Pearson, and Shwingruber, 2014).

Solomon Four-Group Persistence Post-tests will be used in this study to examine the short-and long-term effects of the instructional tactics (Campbell & Stanley, 1963). This framework provides a comprehensive understanding of how successfully STEM training encourages critical thinking, and it will serve as a roadmap for future educational efforts. By encouraging students to shift their focus from experimental to abstract reasoning, the STEM method of instruction specifically supports Piaget's theory of learning. According to Yenlimex and Erosy (2008), STEM-based approach promotes critical and collaborative problem-solving skills, cognitive flexibility, and the creation of new ideas based on preexisting information. The 7E cognitive Cycle can help students develop, apply, and improve their educational results, all of which can foster critical thinking, even if it is currently rare in STEM education (Kapila & Iskander, 2015). By encouraging students to use their information practically, this experimental technique helps them to better strengthen their critical thinking (Cakir & Altun Yalcin, 2021).

As a result of global scientific advancements, STEM approach was created to help pupils think critical and solve problems creatively (Kuenzi, 2008). Cinar et al. (2016) stress that a STEM education helps students acquire 21st century skills by allowing them to apply abstract concepts to practical problems. Akgunduz (2017) asserts that by incorporating STEM instruction into national curricula, nations may develop innovative leaders who will advance technological and economic progress.

Science and engineering schooling in Pakistan has the ability to significantly boost the country's development by introducing students to these fields. According to Bal and Bedir (2021), this experience could improve the country's ability to conduct scientific research, technology, and economic competitiveness. Emphasizing STEM education, according to Altan (2017), meets the demand for a skilled work force and promotes innovative and economic progress. The necessity to abandon antiquated rote learning techniques is highlighted by this study, which investigates how a STEM-based approach for Pakistani education may help elementary school pupils develop their critical thinking skills. Stakeholders, educators, and lawmakers will gain a better understanding of how to incorporate STEM-based learning to enhance overall educational results thanks to the findings.

There are multiple reasons why this study is significant. The results of this study could impact instructive practices and strategies in two ways; first, it contributes to the small quantity of published work on the topic by providing valuable insights into the way STEM instruction in Pakistan develops critical expertise; second, it assists in aligning methods of instruction with the demands of the educational system of the twenty-first century. The study also examines the impact of STEM education on students' attitudes, as evidence suggests that students who engage in STEM activities are more enthusiastic about studying (Bybee, 2010).

Last but not least, the information acquired from this study can help Pakistani teacher preparation programs. Teachers will be better equipped to use successful teaching strategies if they understand how STEM-based learning may encourage analytical thinking and student's involvement. More capable and driven educators who can inspire students and deliver top-notch STEM approach will most likely result from this.

2 Literature Review

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Critical Thinking It is a complicated process that occurs both internally, within a person's cognitive functioning, and externally, through the educational environment and teaching strategies. Critical thinking skills are developed and enhanced through the cooperation of two pillars: extrinsic educational institutions and intrinsic cognitive processes.

Mechanisms of Information Evaluation in the Internal Brain The cognitive processes that go into critical thinking enable one to analyze and evaluate information, reflect on what has been learned, and delve deeply into problems. Being open-minded is crucial to this approach because it dispels prejudices and allows people to view things from various perspectives (Facione, 2015). Fundamental components of critical thinking include the capacity for problem-solving, reasoning through intricate situations, and assessing many points of view (Halpern, 2014). Furthermore, developing thinking critically as a mental habit requires reflecting on one's own educational experiences and applying newly acquired knowledge in practical contexts (Dewey, 1933). To evaluate one's own beliefs and bolster one's logic, collaboration with others is another essential component of critical thinking (Paul & Elder, 2019). Inventive and critical thinkers can investigate new ideas and come up with inventive solutions to issues. Last but not least, the ability to communicate clearly and effectively demonstrates the ability to think critically and to present ideas in an ordered and cohesive manner (Ennis, 1996). These internal mechanisms support the development of critical thinking skills and form the foundation for how people approach problem-solving in diverse contexts.

Promoting Critical Thinking Outside of the Classroom Internal elements like learning environments and instructional strategies have a big impact on and improve critical thinking skills, even if they are an internal activity. According to Brookfield (2012), critical thinking must be included into every subject area in the classroom if pupils are to continuously acquire higher-order thinking skills. This suggests that critical thinking should not be restricted to just one topic area should be included into all of them to help students develop a more holistic intellectual framework (Zohar and Dori, 2003).

For critical thinking to be promoted from the outside in, schools must be made safe and free from intellectual danger. A study by Brookfield (2012), learners need to be free to voice their thoughts and take part in critical discussions without fear of criticism or failure. This kind of environment

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encourages students to think critically, explore new ideas, and take measured risks. Another important consideration is time. Students require this space to gradually hone their critical thinking skills by practice and discussions in the classroom that refute preconceived notions (Paul & Elder, 2019).

Students can expand their perspective and apply critical thinking to a variety of problems when they are given repeated opportunities to practice higher-order thinking in diverse contests. These opportunities can be achieved through inquiry-based learning, problem-based learning, or group discussions (Zohar & Dori, 2003). Additionally, encouraging academic discourse creates an intellectual environment where students can have discussions that improve critical thinking, enabling introspection, discussion, and a more thorough comprehension of the subject matter (Brookfield, 2012).

The process of developing critical thinking skills is dynamic and occurs both internally in the mind and outside in educational settings. Internally, reasoning, problem-solving, and teamwork are the cognitive processes that people critical thinking. On the outside, educators are crucial in promoting these skills by establishing safe learning environments and incorporating critical thinking skills into subject areas. All of these external and internal processes work together to help students improve their critical thinking skills holistically. Critical thinking is a multifaceted cognitive skill that involves five basic sub-categories: deduction, assumption, interpretation, argument, and inference. Because it enables people to critically evaluate information and make well-informed decisions, it is crucial for both academic performance and lifetime learning (Halpern, 2024). The worldwide education system is emphasizing the acquisition of critical thinking skills more and more in order to prepare students for the multifaceted nature of the twenty-first century.

One of the primary objectives of science education is to foster critical thinking. Thus, scientific classes can teach students how to think critically. A learning environment that will promote the development of thinking skills is necessary for this, though, as well as an efficient teaching and learning technique. According to Kek and Huijser (2011), the learning environment and instructional tactics should support the learner’s that information in order to find solutions. Considering this, students must be receive assistance in homing their critical thinking skill, among other things. The learning environment needs to be modified to give students the opportunity to take charge of their education and collaborate to find a solution (Johns, 2012). According to

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Duraon, Limback, and Waugh (2006), the idea behind critical thinking is based on Benjamin Bloom's work (Bloom, 1956), who divided the cognitive domain into six levels, each of which correlated to a person's level of cognitive capacity. Critical and scientific thinking are improved by higher order thinking activities, according to Schulz and Schulz and Fitz Patrick (2016). According to Kuhn (2002), every day, higher-order thinking is what humans do every day when they think scenically. STEM exercises may aid students in developing critical thinking, which is a term that is identical with scientific thinking, because they are genuine and based on actual circumstances.

Due to its inclusion in Evaluation and Instruction of 21CC (ATC21S) and Hart Research Associates' (2013) list of five key learning objectives, critical thinking has received a lot of attention recently as a critical 21st century skill. Critical thinking is also essential for employment 21st century skill in recent years. According to white papers released by the World Economic Forum (WEF) and the Organization for Economic-Cooperation and Development (OECD), critical thinking will also be necessary for employment in the future due to the way that technological advancement are changing the nature of work (Sternberg, 2013). The reason critical thinking matter is that employers value it. The most crucial elements for employee success in today's intricately linked workplace are interpersonal skills like cooperation, communication, creativity (critical thinking), and flexibility, according to 1709 CEOs, general managers, and senior public sector officials in a 2012 IBM Global CEO study (IBM, 2012).

The successful application of critical thinking instruction is hampered by the lack of a clear definition of the term. The concept of critical thinking has been around for many years. As an example: "a desire to seek, tolerance for doubt, a preference for mediating, a slowness to assert, a readiness to consider, caution when disposing of and organizing thoughts, and hatred for all forms of imposters." Another definition "the art of thinking about thinking while thinking in order to make thinking better" (Richard Paul & Linda Elder, 2006). There are several ways to include critical thinking into curricula as a result of varying definitions and perspectives of the concept. Hard science and social science programs teach the scientific method because they often think it's the best approach to teach critical thinking. The growth of rational thought, which has its origins in the works of Aristotle, Plato, and Socrates, is the main goal of critical thinking education in humanities subjects and philosophy (Robert & Ennis, 1996).

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Benefits of STEM approach STEM, which stands for science, technology, engineering, and mathematics, is becoming more and more popular in the commercial and educational sectors. This is justified by the fact that jobs centered around STEM disciplines in the future will surely require 21st century skills like creativity, critical thinking, problem-solving, collaboration, and cultural understanding. STEM education enhances the acquisition of 21st century skills when it is implemented properly.

While a STEM education approach is important, it is not enough on its own. Integrating sustainability and environmental education into STEM education is essential to a successful future redesign. For the benefit of future generations, it is our responsibility to make sure that we are moving in the right direction and that our current course is sustainable. One helpful tactic for achieving this is to incorporate the Sustainable Development Goals (SDGs) into STEM-based sustainability teaching. STEM education can address global issues like poverty, injustice, and climate change with the help of these 17 aims. A STEM approach has several benefits for students' overall performance, including the following:

Improves Creativity Thinking outside the box is a phrase we've all heard before, right? Actually, the core of a STEM education is creativity. Students majoring in STEM are urged to develop original concepts and adopt an interdisciplinary strategy while resolving complicated problems.

Increases Team Collaboration Teams are frequently needed in the real world and at work to solve and finish complex challenges. In light of this, STEM education places an emphasis on cooperation and collaboration in its curricula to teach pupils the values of leadership and communication in attaining shared objects.

Develops Communication Skills Of all the life skills, communication skills are arguably the most crucial. The key to success in a child's life as they become older will be having the capacity to communicate complicated ideas to others while also learning from one another. Group STEM activities encourage social skills like active listening and open-mindedness, as well as the ability to provide and accept constructive criticism.

Empowers Critical Thinking Skills The type of content provided in a STEM education is concentrated on encouraging children's critical thinking. Critical thinking is the process of conceptualizing, applying, analyzing, and evaluating knowledge through communication,

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reflection, experience, and observation. Consequently, teachers will encourage students to respond to questions and wok through challenges by actively engaging with the content to comprehend the problem at hand and find a logical solution. Situations like these early in their education will better prepare students for their futures because they better mirror what is expected of them in the industry.

Boosts Curiosity STEM education is all about encouraging young children to ask "why" and "how" questions. Student exploration and innovative problem-solving will be facilitated by the opportunity to use STEM. Curiosity and involvement on the part of students are what promote creativity and discoveries.

Improves Cognitive Skills The mental abilities known as cognitive capabilities improve reading, thinking, and learning. It may be worked out and strengthened through training, much like a muscle. Students who study STEM course in elementary school can hone their cognitive abilities and lean the fundamentals of coding and engineering. The cognitive skills of children will be developed using this method, which will also help them solve problems more quickly and effectively.

Introduces STEM careers at early ages According to studies, the majority of occupations will be focused on STEM fields or include STEM elements. Early STEM exposure exposes children to a world of opportunities and develops the abilities necessary for success in the 21st century.

Teaches how to take initiative Learning is becoming more enjoyable as a process. STEM equips inquisitive students with the abilities to approach problems with confidence, promotes a more positive attitude towards learning, increase student self-confidence, and dissipates negative biases that support the development of individuals who are inquisitive, self-assured, and proactive when facing difficulties.

Enhances media literacy STEM students, unlike those in traditional curriculum, learn by inquiry and study. Inquiry calls for students to participate in hands-on learning by formulating their own central questions and looking for solutions through reading and research. They are able to use what they have learned in their everyday lives in this way.

Boosts social-emotional learning (SEL) Happiness and success in life are a result of social and emotional intelligence. Before they participate activity in society, youngsters are encouraged to develop their SEL abilities through STEM education. In addition to fostering personal growth, integrating SEL practice into instruction helps students advance their academic learning (Imran. Gunduz, 2023).

Previous Studies on STEM and Critical Thinking Empirical studies have shown that the STEM-based instruction improves critical thinking. According to a meta-analysis by Becker and Park (2011), students' analytical reasoning and problem-solving skills were considerably increased in STEM programs when compared to traditional educational approaches. Similarly, STEM activities fosters teamwork and analytical thinking, which strengthens critical thinking skills (Roberts and Cantu, 2012).

3 Material and Procedures

Design of Research The study evaluates the effectiveness of the STEM approach in improving elementary school children's critical thinking skills using pretesting and treatment, Solomon Four-Group design is used for adjusting confounding factors. A more accurate assessment of the instructional influence is made possible by this method, which uses both pretested and non-pretested groups and randomizes participants (Solomon RL, 1949; Campbell & Stanley, 1963)." (Table 1)

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.

Participants In a study conducted at the public sector school in district Faisalabad, Pakistan, 184 eighth-grade elementary students, ages 12 to 14, participated. To guarantee equal representation, computer–generated random number tables and basic random selection were used to gather the data. The study's low generalizability stems from its sole emphasis on a particular institution, where control groups received traditional instruction and experimental groups received STEM-based approach.

Procedure The STEM-based instructional approach, following the Next Generation Science Standards, incorporates inquiry-based, discover-based, project-based, problem-based learning, multidisciplinary projects, and practical exercises, compared to traditional textbook-based learning. Posttests evaluate critical thinking skills retention.

Measures Elementary 8^{th} grade students' previous knowledge was checked by a pretest given to both groups G1 and G3. STEM-based instructions were provided to G1 and G3 separately for 7 weeks and G2 and G4 were taught under conventional methods. Data were collected using adapted Watson-Glaser Critical Thinking Skills Appraisal because of its proven validity and reliability, administrated as pretests, posttests, and retention posttests (Watson & Glaser, 2006). Students' critical thinking skills and knowledge were assessed and evaluated by 80 MCQ-based questions. The study modified a critical thinking test for eighth-grade students, assessing deduction, inference, interpretation, argument, and assumption, ensuring their ability to take it.

Data Analysis The data analysis process compares pretest, posttest, and retention posttest results of experimental and control groups using Shapiro-Wilk and Wilcoxon's tests, confirming homogeneity and normality. As necessary, data transformations were applied to validate these hypothesis. The implications of modifications throughout time as well as between groups was evaluated using two statistical methods: ANOVA and the t-test.

4 Results

Pretest, Posttest, and Retention Posttest Results As evidenced by the statistically significant improvement in critical thinking scores in Group 1 (the experimental group) and the effect size (Cohen's d = 2.53), the STEM approach has a huge practical impact on improving students' critical thinking skills. The retention posttest's apparent improvement over time provides additional evidence of the instructional method's long-lasting impacts.

Group 1: Critical Thinking Skills (STEM Intervention Group) Group 1 received the STEM-based instructive method, and their critical thinking scores improved considerably from the pretest (M = 36.4, SD = 7.03) to the posttest (M = 69.1, SD = 4.41). The results of the paired t-test, which

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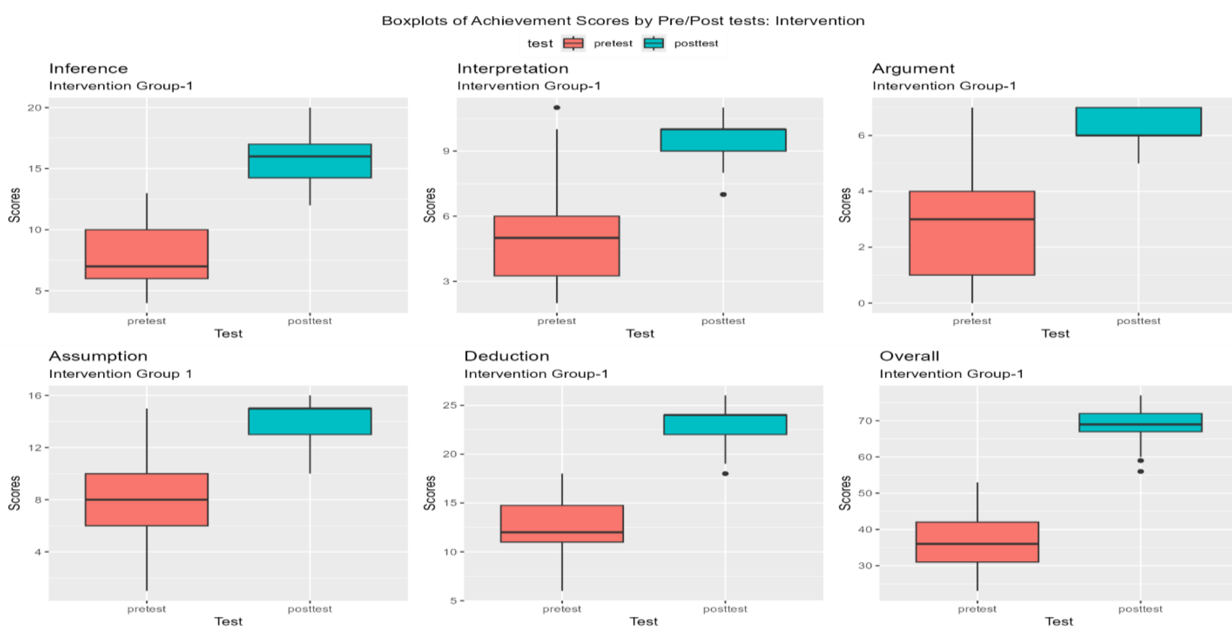
displayed a mean difference of 32.65, a t-value of 31.219 (df = 45, $p < 2.2e-16$), and a 95% confidence interval ranging from 30.55 to 34.76, validated the statistical significance of the improvement (Table 1).

Table 1 Summary of Pretest and Posttest Scores

Test	Mean	(SD)	(N)	(SE)
Pretest	36.4	7.03	46	1.04
Posttest	69.1	4.41	46	0.650

Table 2 Paired t-test Results

Statistic	Value
t-value	31.219
Degree of Freedom (df)	45
p-value	<2.2e-16
Mean Difference	32.65217
95% Confidence Interval	(30.54560, 34.75875)



Group 2: Critical Thinking Skills (Traditional Instruction Group)

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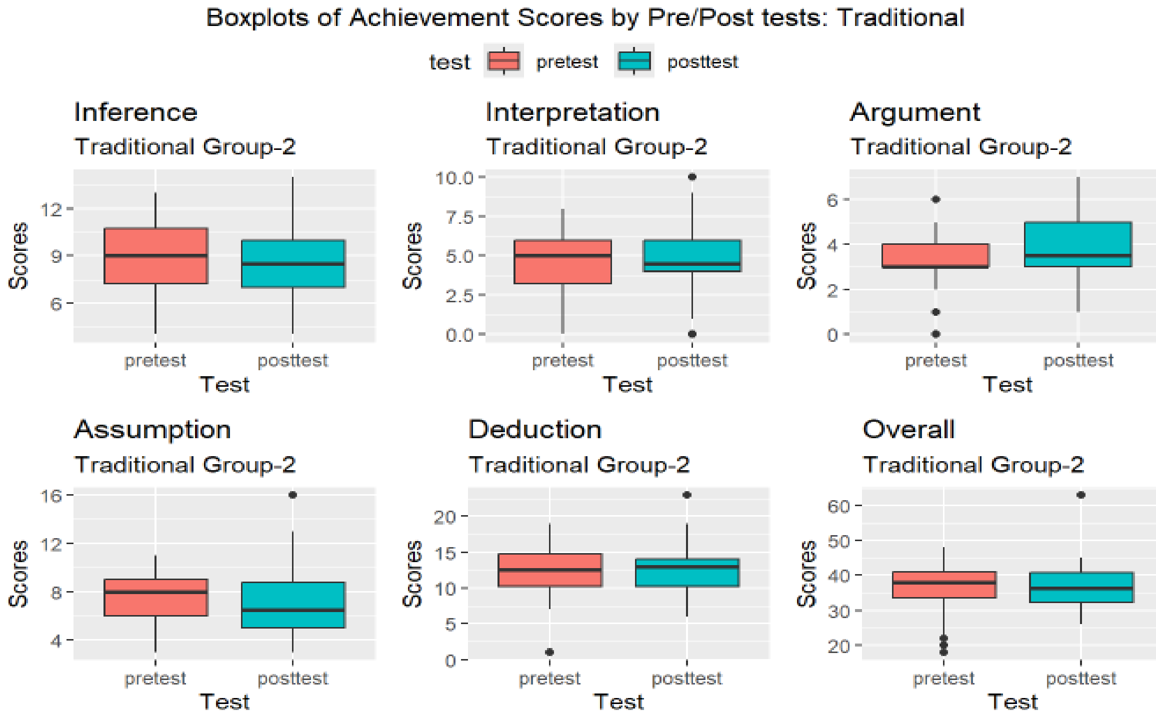
Group 2's critical thinking skills, which were taught in a typical manner, barely altered between the pretest (M = 36.4, SD = 6.93) and posttest (M = 36.7, SD = 6.66). The paired t-test revealed no statistically significant differential between the pretest and posttest scores (t-value = 0.212, df = 45, p = 0.8332). A 95% confidence interval between -2.59 and 3.20 is presented alongside the mean difference of 0.304 in Table 2.

Table 1 Summary of Pretest and Posttest Scores

Test	Mean	(SD)	(N)	(SE)
Pretest	36.4	6.93	46	1.02
Posttest	36.7	6.66	46	0.982

Table 2 Paired t-test Results

Statistic	Value
t-value	0.21186
Degree of Freedom (df)	45
p-value	0.8332
Mean Difference	0.3043478
95% Confidence Interval	(-2.588989, 3.197684)



Group 3 vs. Group 4: Critical Thinking Skills (Traditional vs. Intervention)

The comparison of Group 3 STEM intervention and Group 4 conventional method reveals significant differences in the outcomes of both educational methodologies. Compared to Group 3, the interventional group, which displayed posttest results of M = 36.4, SD = 5.74, and SD = 10.8, furthermore, the Welch Two-Sample t-test confirmed a statistically significant difference between the means of the two groups, yielding a t-value of 10.724 (df = 68.555, p = 2.623e-16) and a 95% confidence interval of 15.78 to 22.95. The F-test to compare two variances yielded an F-value of 3.5383 (p = 4.375e-05), indicating a substantial variance between the groups. Compared to the traditional group's mean score of 36.37, the intervention groups' mean score is much higher at 55.72 (Table 3).

Table 1 Summary of Traditional and Intervention Scores

Test	Mean	(SD)	(N)	(SE)
Pretest	36.4	5.74	46	0.847
Posttest	55.7	10.8	46	1.59

Table 2 F-test to compare two variances

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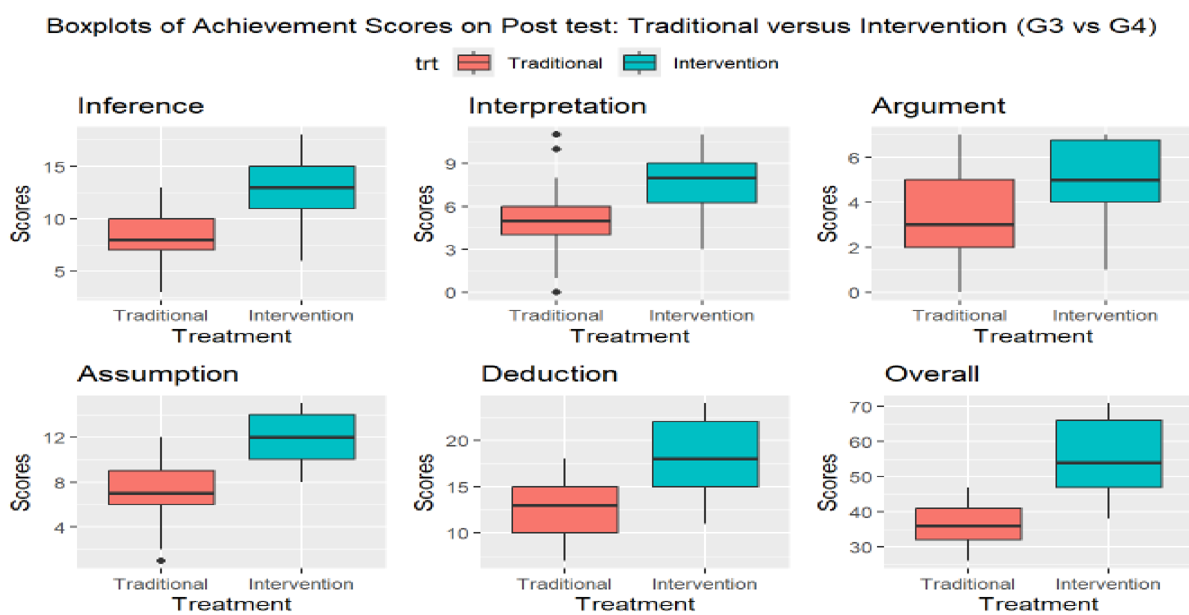
Statistic	Value
F-value	3.5383
Numerator (df)	45
Denominator (df)	45
p-value	4.375e-0.5
95% Confidence Interval	(1.9557801, 6.394588)
Ratio of Variance	3.538267

Table 3 Welch Two Sample t-test

Statistic	Value
t-value	10.724
Degree of Freedom (df)	68.555
p-value	2.623e-16
95% Confidence Interval	(15.7815, 22.94750)
Mean in group intervention	55.71739
Mean in group traditional	36.36957



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Comparison between the Control and Experimental Groups The STEM approach effectively enhances critical thinking skills, with experimental groups performing better on posttest and retention assessments. However, confounding factors like instructor competence, classroom settings, and student participation may affect results, necessitating further investigation.

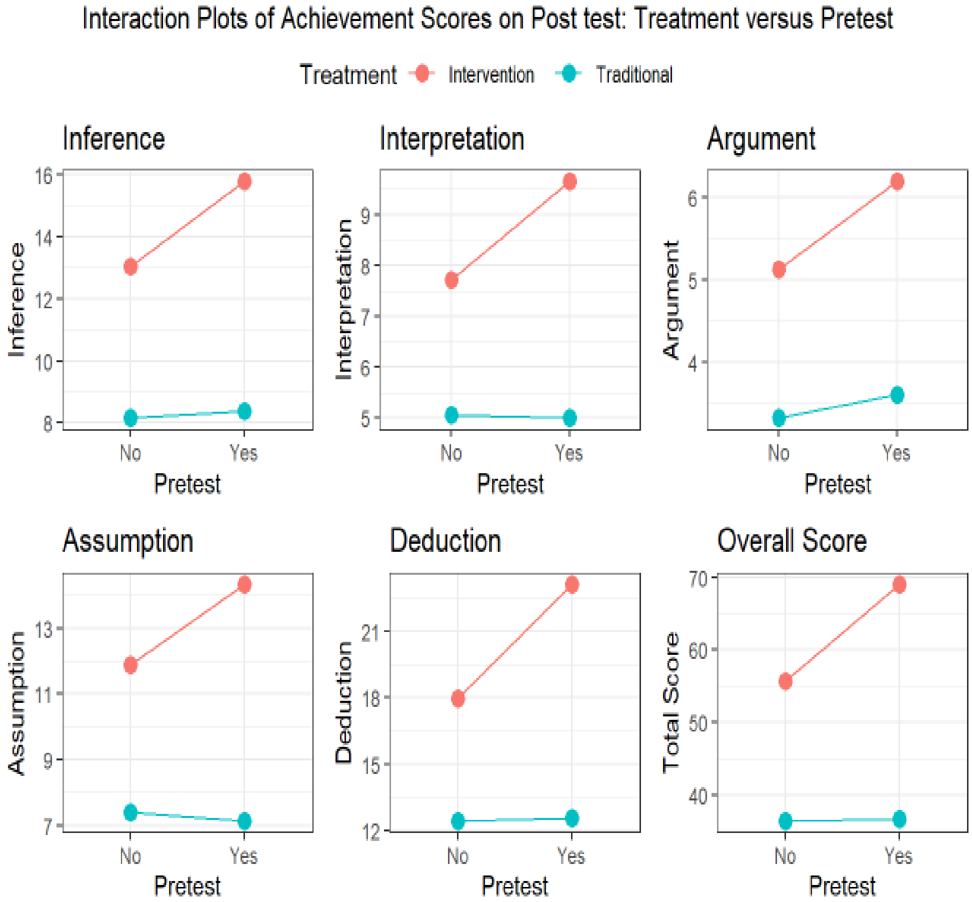
Pretest Sensitization Effect Analysis The study evaluated the impact of pretest sensitization on posttest outcomes by comparing groups that received a pretest with those that did not. Specifically, the experimental group that received the pretest (Group 1) showed a significant improvement in posttest scores ($M = 69.1$, SD 4.41) in comparison to the group that did not receive the pretest (Group 3), which also showed a significant rise ($M = 55.7$, $SD = 10.8$), albeit significantly lower. Even after controlling for pretest results, this indicates that the STEM-based approach itself had a substantial effect on posttest scores, suggesting that pretest experience may have further enhanced students' awareness and focus, resulting in greater performance ($F = 305.82$, $p < 2.2e-16$). This implies that the observed improvements in critical thinking were primarily due to the educational strategy rather than merely pretest sensitization. Practically speaking, the observed pretest sensitization effect may have been influenced by additional elements including students' motivation or prior exposure to critical thinking concepts, suggesting a complex relationship involving pretest exposure and instructional effectiveness.

Statistical Analysis Critical thinking scores were significantly impacted by the type of education (traditional vs. STEM), according to the results of the Analysis of Variance (ANOVA). According to the ANOVA results, the STEM approach led to a higher mean rise in critical thinking scores than the traditional method. In particular, the relationship between posttest results and accomplishment was important. The two-way ANOVA results showed that the pretest ($F = 40.281$, $p = 1.735e-09$) and the treatment approach (STEM vs. traditional) had a significant effect on the posttest scores. With a high F value of 576.214 ($p < 2.2e-16$) for the treatment strategy, the residual analysis further reinforced the robustness of these results by demonstrating a considerable impact of a STEM-based approach on the development of critical thinking.

Analysis of Variance (ANOVA) Two-way ANOVA

Interaction of Achievement on Posttest Scores: Treatment vs. Pretest (Overall)

Sources	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Pretest	1	2150.2	2150.2	40.281	1.735e-09
Treatment (trt)	1	30758.9	30758.9	576.214	<2.2e-16
Pretest	1	1950.0	1950.0	36.530	8.453e-09
Residuals	180	9608.6	53.4		



Posttest vs. retention Posttest for STEM Intervention Groups (G1 and G3) The posttest and retention posttest descriptive statistics for the STEM intervention groups (M = 62.4, SD = 10.6) and M = 62.8, SD = 10.3) revealed consistent scores with little variation between the two tests, suggesting sustained critical thinking skills across time.

Descriptive Statistic for Posttest and Retention Posttest

Test	Mean	(SD)	(N)	(SE)
Posttest	62.4	10.6	46	1.11
Ret. Posttest	62.8	10.3	46	1.07

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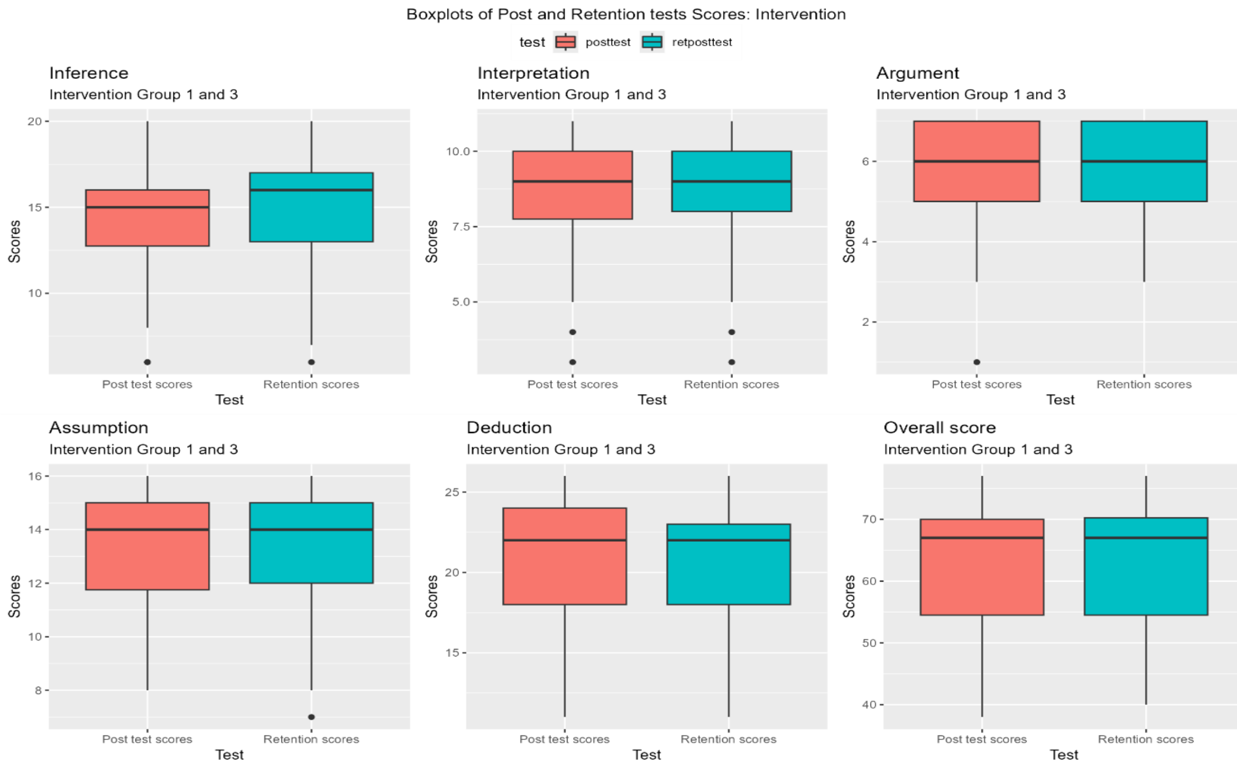

Posttest vs. retention Posttest for Traditional Instruction Groups (G2 and G4)

The retention posttest (M = 36.7, SD = 6.04) and posttest (M = 36.5, SD = 6.19) scores in the traditional instruction groups similarly showed little variation and were consistent. Comparing these groups' overall low scores to those of the experimental groups, however, demonstrates how unsuccessful traditional training is at fostering and maintaining critical thinking skills.

Descriptive Statistic for Posttest and Retention Posttest

Test	Mean	(SD)	(N)	(SE)
Posttest	36.5	6.19	46	0.645
Ret. Posttest	36.7	6.04	46	0.629

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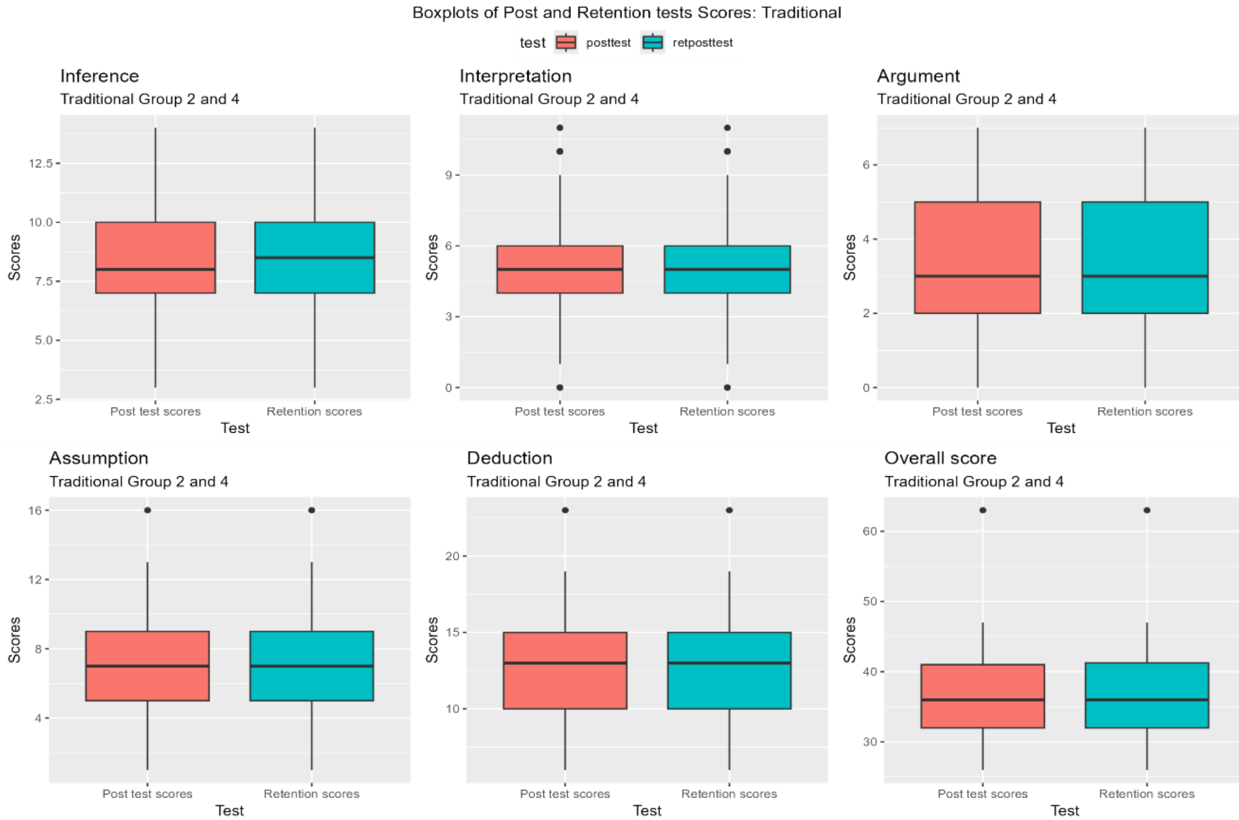

5 Discussion

Interpretation of Results The study's conclusions highlight the degree to which eighth graders' critical thinking skills can be enhanced by a STEM-based curriculum. A comprehensive assessment of the possible pretest sensitization effect was made possible by the Solomon Four-Group design, which enhanced the validity of the results that were reported. The STEM groups' significant improvements in critical thinking align with earlier studies showing how inquiry-based learning can increase cognitive abilities (Lai, 2011). Though the beginning scores of the traditional groups were identical, the lack of improvement in the groups implies that the cognitive demands of developing critical thinking skills may not be sufficiently addressed by conventional techniques.

Effectiveness of STEM approach The results unequivocally demonstrate that, in comparison to traditional teaching methods, the STEM approach significantly improves students' critical thinking skills. The notable improvement in posttest scores observed in Groups 1 (Pretest + STEM approach) and 3 (STEM only) supports this finding. Considering an overall difference of (M = 32.65) and a p-value < 2.2e-16, Group 1 demonstrated a substantial rise in critical thinking scores.

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Comparably, Group 3, which was taught using the STEM technique but did not get the pretest, showed a considerable improvement, with a posttest mean of 55.7 compared to 36.4 for the group that used the traditional method (Group 4). Despite the lack of a pretest, these findings imply that the STEM approach is naturally beneficial for enhancing critical thinking skills.

Pretest Sensitization Effects The results of the study were impacted by pretest sensitization, as indicted by the substantial interaction effect uncovered by the two-way ANOVA ($F = 36.530$, $p < 8.453e\text{-}09$). Specifically, it appears that the pretest enhanced students' critical thinking skills, which in turn increased their openness to STEM-focused training. The higher posttest scores of Group 1 (pretest + STEM) compared to Group 3 (STEM only) show this. Despite the fact that both groups had significant gains in thinking critically, Group 1 shown an additional boost, indicating that the prior test sensitization effect made the STEM approach more successful.

On the other hand, regardless of prior knowledge, the previous approach showed no discernible improvement in critical thinking. The STEM method is superior, as seen by the lack of progress in Group 2 (Pretest + Traditional) and 4 (Traditional only). As seen by the substantial p-values ($p = 0.8332$ for Group 2), pretest sensitization had little effect on the efficacy of traditional training, suggesting that there is no variation between pretest and posttest results in these groups.

Retention (Advantages in Critical Thinking) The comparison between the posttest and retention posttest for Groups 1 and 3 demonstrates that critical thinking skills are sustained over time, suggesting that the benefits of the STEM approach are enduring. Students' critical thinking skills were retained and possibly enhanced outside of the immediate learning session, as seen by the slight increase in mean scores from the posttest to the retention posttest ($M = 62.4$ to 62.8) this ongoing effect shows how the STEM method affects students' cognitive development over the long run.

Implications Since these findings have important ramifications for teaching strategies, STEM approaches must be incorporated into the curriculum to promote critical thinking skills. Teachers and legislators should take into account the advantages of STEM-based approach while preparing pupils for future difficulties.

Limitation One of the study's shortcomings is the incredibly shot intervention time frame. Future studies ought to examine how STEM-based instruction affects critical thinking skills over the long run. Furthermore, the study's focus on a particular age range and educational setting may limit how broadly the results may be applied.

Recommendations for Upcoming Studies

Pretest Sensitization The processes behind pretest sensitization and their interactions with different teaching modalities should be the focus of future research. Further insight into how to create successful educational interventions may come from examining if various pretest formats (such as those that emphasize consciousness vs. skills evaluation) have differing degrees of sensitization effects. To broaden the scope of the findings, future studies should examine whether the benefits mentioned are applicable to different age groups, individuals, or learning contexts.

Examine a variety of Populations Conduct research with diverse student demographics in a range of educational settings to validate and broaden the findings.

Look at Long-Term Impacts Studies that follow participants over time may provide insight into how cognitive skills, including critical thinking, evolve and endure, as well as how they affect students' academic and career trajectories.

Look at Specific STEM Elements Learn which specific elements of the STEM approach—like integrating technology and doing practical experiments—are best for fostering critical thinking skills.

Assess Implementation Obligation To ensure reliability and consistency in research results, create and execute tools to evaluate the implementation fidelity of STEM education.

Investigate the Views of Teacher Use qualitative research to better understand the challenges and experiences educators have while implementing STEM-based teaching methods.

6 Conclusions

The study offers strong evidence that STEM-based training effectively improves elementary school students' critical thinking skills, which has implications for curriculum development and educational policy. As per the findings, including a STEM methodology into preschool classrooms could be useful strategy for encouraging the growth of critical thinking skills, which are crucial for future success in both the classroom and the industry.

Importance of STEM in Developing Critical Thinking The demands of a technologically sophisticated culture are changing faster than ever before, making critical thinking and problem-solving skills more crucial than ever for today's youth. Giving young people the skills they need to meet the requirements of today's job market requires STEM instruction in the classroom. Students who receive early training in these skills are better are better equipped to handle the challenges of a globe that is changing quickly and develop into creative thinkers and problem-solving individuals in a range of professions. The STEM approach is important for developing cognitive skills, creative thinking, and adaptability, which are critical for success in the 21st century, according to study (Bybee, 2013; National Research Council, 2011).

Final Thoughts In conclusion, the STEM approach is a potential strategy for enhancing critical thinking skills in elementary school curriculum. As educators and lawmakers strive to prepare children for the difficulties of the twenty-first century, the STEM approach should be a key component of education reform measures.

Disclosure Statement

There are no conflicts of interest that the authors reveal.

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