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Statistical Analysis of Teachers Implement STEM-Fun Mathematics Story Test Media on 2C's Critical Thinking Ability and Collaboration Skills

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ABSTRACT

This study examined the implementation of STEM-Fun Mathematics Story Test Media in social arithmetic learning by focusing on three aspects: teacher implementation of the media, observed changes in students' critical thinking and collaboration skills, and students' responses to the learning experience. The study employed a one-group pretest-posttest design involving 32 Grade VII junior high school students. Data were collected using a teacher activity observation sheet, a student collaboration observation sheet, critical thinking pretest and posttest tasks, and a student response questionnaire. The results showed that the teacher implemented the learning activities in the very good category, with an overall score of 85.68%. Students' collaboration skills also showed positive development, increasing from 81% at the first meeting to 93% at the second meeting. Critical thinking scores were significantly higher in the posttest than in the pretest, with an N-gain score of 0.714, categorized as high. In addition, students demonstrated a very positive response to the learning experience, with an average response score of 90.18%. These findings indicate that STEM-Fun Mathematics Story Test Media was successfully implemented in social arithmetic learning and was accompanied by positive changes in students' critical thinking and collaboration skills. Given the one-group design, these findings should be interpreted as changes observed within the participating group rather than as definitive causal effects of the intervention.

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1. INTRODUCTION

In the era of modern education, teachers are required to be able to integrate technology into the learning process, especially those that are popular in using STEM (Science, Technology, Engineering, and Mathematics) based learning media. One of the innovations in this study is STEM-Fun Mathematics Story Test Media, a STEM-based learning media with interesting and fun story problems.

This media is designed to improve students' mathematics skills by solving challenging interactive story problems, allowing students to apply mathematical concepts in relevant real-world contexts. Moreover, STEM-Fun Mathematics Story Test Media aims to develop critical thinking and collaboration skills among students. STEM-based digital media have been shown to enhance critical thinking significantly (Rohmah et al., 2023; Lubna et al., 2023; Rachmadtullah et al., 2023; Sumawati et al., 2021) and collaboration skills (Zainil et al., 2024; Siahaan et al., 2020) among students.

Integrating STEM-Fun Mathematics Story Test Media into the learning process not only enhances conceptual understanding in these areas but also plays a vital role in developing students' critical thinking and collaboration skills. For instance, Topsakal et al. (2022) demonstrated that problem-based STEM education significantly improves students' critical thinking tendencies and their perceptions of problem-solving skills, reinforcing that a critical thinking environment fosters better expression of ideas in classroom settings. A study by Gencer and Doğan (2020) revealed that the use of STEM-based media significantly improves students' critical thinking skills. Critical thinking skills can be improved by applying the appropriate learning model (Pitorini et al., 2024), as a well-structured learning environment that integrates STEM principles has been shown to significantly improve students' analytical abilities. A study by Hacıoğlu and Gülhan (2021) also supports this view by showing that carefully designed STEM-based media can effectively develop students' critical thinking skills.

In addition to critical thinking skills, collaboration is another essential skill acquired through implementing STEM-based digital media in education. Wibowo et al. (2022) showed how the use of Virtual Microscopic Simulation (VMS) in STEM learning can facilitate collaboration between students. This activity requires students to work in teams to solve complex problems, improving their communication and teamwork skills. Reyna and Meier (2020) also emphasized the importance of co-creating knowledge through STEM-based digital media. They argued that the use of STEM-based digital media improves students' technical skills and strengthens their ability to work in diverse teams, which is very important in today's globalized world. With increased collaboration between students from different backgrounds, they can learn to negotiate solutions and collaborate effectively in a broader context. Hebebci and Usta (2022) stated that integrated STEM practices allow students to engage in scientific inquiry and collaborative learning, which is essential for improving critical thinking dispositions. Furthermore, Kavoura echoes the importance of creating a collaborative culture in STEM education, illustrating how technology-enhanced projects can cultivate student communication and project management skills (Kavoura et al., 2023). Guntur (2023) stated that interactive STEM-based learning media can create a fun learning experience and encourage students to collaborate actively. The interactive STEM-based learning media aligns with constructivist education principles, emphasising the importance of learning based on real experiences and student collaboration.

Critical thinking and collaboration skills are essential in the recovery efforts of the global education crisis known as the "Learning Loss Generation" which refers to the loss of learning opportunities for students due to learning disruptions during the COVID-19 pandemic. This crisis highlights how important these two skills are to address the decline in the quality of education and help students adapt to the new learning environment. Research shows that the pandemic has caused many students to struggle to adapt, increasing the need for critical thinking and collaboration skills (Aristovnik et al., 2020). In addition, studies have also shown that educators' confidence in managing change during the pandemic has a significant impact on their engagement and effectiveness in teaching (Aljohani & Agarwal, 2022). Therefore, professional development that focuses on improving educators' abilities to teach critical thinking and collaboration is essential to address these challenges. One way is to integrate technology and digital platforms that support students' learning experiences (Almaida & Djamdjuri, 2021). In this context, STEM-Fun Mathematics Story Test Media is a very relevant innovation. The use of this media not only makes mathematics learning more interesting and fun, but also provides an opportunity for students to develop critical thinking and collaboration skills through interactive story problems.

The integration of STEM-based digital media provides opportunities to create interactive learning environments in which students engage with contextual problems, use digital resources, and construct

solutions through active participation. Digital and game-based environments can increase student engagement and provide representations that support the understanding of complex concepts . Similarly, inquiry-oriented digital resources can support motivation and learning efficiency within STEM learning environments (Hrynevych et al., 2021). However, the educational value of digital media depends not merely on the presence of technology but also on how teachers organize learning activities and guide students in interpreting problems, discussing possible solutions, and communicating their reasoning (Johnston, 2019). Such learning environments may also provide opportunities for systems thinking and collaborative problem solving (Subramaniam et al., 2012).

Within this learning environment, critical thinking and collaboration should not be treated as isolated competencies. Solving contextual STEM problems requires students to interpret information, analyze relationships, evaluate possible solutions, draw conclusions, and communicate their reasoning with others. Previous studies have shown that problem-based and STEM-oriented learning can support critical thinking and problem-solving processes (Gencer & Doğan, 2020; Hacioğlu & Gülhan, 2021; Topsakal et al., 2022). At the same time, STEM learning provides opportunities for students to work together, negotiate ideas, share responsibilities, and construct solutions collectively (Hebebci̇ & Usta, 2022; Kavoura et al., 2023; Reyna & Meier, 2020; Wibowo et al., 2022). Thus, critical thinking represents the cognitive processes used to examine and justify solutions, whereas collaboration provides the social process through which ideas are discussed, evaluated, and refined.

In this study, critical thinking is operationalized through interpretation, analysis, evaluation, inference, explanation, and self-regulation, following the framework used in previous studies (Dwyer & Walsh, 2020; Rohmah et al., 2023; Shida et al., 2023; Sukriyah & Juniati, 2023; Ubaidillah et al., 2023). Collaboration is examined through students' active contribution, productive work, compromise and flexibility, responsibility, and respect for other group members, drawing on the collaboration frameworks discussed by Redhana (2019) and Trilling & Fadel (2009), and Greenstein as cited in (Indrawan et al., 2021). These dimensions allow the implementation of STEM-Fun Mathematics Story Test Media to be examined in terms of both students' individual reasoning and their participation in collaborative mathematical problem solving.

Despite the growing use of STEM-based digital media, the studies reviewed in this research have generally emphasized critical thinking or collaboration as separate learning outcomes, while less attention has been given to learning designs that intentionally connect both competencies through contextual mathematical story problems. This issue is particularly relevant to the social arithmetic context used in this study, where students work with everyday situations such as profit, loss, and discount and are required to understand the information presented in a problem before determining an appropriate mathematical solution. Preliminary observations and interviews in the participating class indicated that students experienced difficulties in interpretation, analysis, evaluation, and inference when solving story problems. Their collaborative performance also showed limitations in flexibility, productivity, and contribution during group activities. These conditions provided the empirical rationale for implementing STEM-Fun Mathematics Story Test Media as a learning environment in which students could engage with contextual mathematical problems while discussing, evaluating, and constructing solutions collaboratively.

Accordingly, the contribution of this study lies in the integration of STEM-based digital media with story-form mathematical tasks in social arithmetic learning while examining critical thinking and collaboration within the same instructional setting. Rather than considering the teacher's implementation process and student outcomes as a single construct, this study distinguishes the implementation of the media by the teacher, the observed changes in students' critical thinking and collaboration skills, and students' responses to the learning experience.

Accordingly, this study focuses on the implementation of STEM-Fun Mathematics Story Test Media in social arithmetic learning by distinguishing the instructional process from the learning outcomes observed among students. Specifically, the study examines how the teacher implements the media, how students' critical thinking and collaboration skills develop during its implementation, and

how students respond to the learning experience. Based on these focuses, the study addresses the following research questions:
RQ-1: How is STEM-Fun Mathematics Story Test Media implemented by the teacher in social arithmetic learning?
RQ-2: What changes in students' critical thinking and collaboration skills are observed following the implementation of STEM-Fun Mathematics Story Test Media?
RQ-3: How do students respond to the implementation of STEM-Fun Mathematics Story Test Media?

2. METHOD

Research Design

This study employed a one-group pretest-posttest design to examine changes in students' critical thinking skills before and after the implementation of STEM-Fun Mathematics Story Test Media. Students completed a critical thinking pretest before the intervention and a posttest after the intervention. During the learning activities, students' collaboration skills and the teacher's implementation of the learning process were observed. STEM-Fun Mathematics Story Test Media was implemented in social arithmetic learning using contextual story problems related to profit, loss, and discount. The research design for assessing students' critical thinking skills is presented in Table 1.

Table 1. One-Group Pretest-Posttest Research Design

Pretest	Treatment	Posttest
O_1	X	O_2

O_1 : Pretest of students' critical thinking skills before the implementation of STEM-Fun Mathematics Story Test Media.
X : Learning using STEM-Fun Mathematics Story Test Media through social arithmetic story problems.
O_2 : Posttest of students' critical thinking skills after the implementation of STEM-Fun Mathematics Story Test Media.

Because this study involved only one group and did not include a comparison or control group, differences between the pretest and posttest cannot be attributed exclusively to the intervention. Other factors occurring during the study may also have contributed to the observed changes. Therefore, the pretest-posttest findings are interpreted as changes observed within the participating group rather than as definitive evidence of a causal effect of STEM-Fun Mathematics Story Test Media. This limitation should be considered when interpreting and generalizing the findings.

Participants

The study was conducted at SMP PGRI 1 Surabaya, East Java, Indonesia. The participants were 32 students from Grade VII-E who were selected based on recommendations from the mathematics teacher and preliminary observations conducted by the researchers. Preliminary observations and interviews indicated that the students experienced difficulties in critical thinking, particularly in interpreting, analyzing, evaluating, and making inferences when solving mathematical story problems. Their collaboration skills also showed limitations in flexibility, productivity, and active contribution during group activities, although the students generally demonstrated respect toward other group members.

Research Instruments

Data were collected using four main instruments: a learning implementation observation sheet to assess the teacher's implementation of STEM-Fun Mathematics Story Test Media, a student collaboration observation sheet, pretest and posttest tasks to assess students' critical thinking skills, and a student response questionnaire.

The critical thinking assessment consisted of three items designed to assess students' reasoning in solving contextual mathematical problems. Critical thinking was examined through indicators including interpretation, analysis, evaluation, inference, explanation, and self-regulation. Students' collaboration was observed through five indicators: active contribution to the group, productive work, compromise and flexibility, responsibility, and respect for other group members.

The student response questionnaire consisted of seven items with four response options: Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). The questionnaire was administered after the implementation to examine students' responses to learning with STEM-Fun Mathematics Story Test Media.

Instrument Validation and Pilot Testing

Before the main study, the learning materials, STEM-Fun Mathematics Story Test Media, and research instruments were subjected to expert validation. The validation involved three experts consisting of two mathematics education lecturers and one mathematics teacher. The validated components included the teaching module, the appearance and content of STEM-Fun Mathematics Story Test Media, the pretest-posttest instrument, the learning implementation observation sheet, the collaboration observation sheet, and the student response questionnaire. Revisions were made based on the validators' recommendations before the instruments were used in the main study.

The pretest-posttest instrument was subsequently piloted with 34 Grade VII-G students from the same school who were not participants in the main study. Item validity was examined using Product Moment correlation. The pilot analysis indicated statistically significant correlations for all three items, and the items were therefore retained for use in the main study.

Internal consistency was also examined using Cronbach's Alpha. The three-item instrument yielded an alpha coefficient of 0.463. This value indicates low internal consistency and should not be interpreted as evidence of adequate reliability. Accordingly, the alpha result is reported transparently as a measurement limitation and should be considered when interpreting the findings obtained from the critical thinking assessment.

Research Procedures

The research procedures followed five main stages: Analysis, Design, Validation, Application, and Conclusion (ADVAC). During the analysis stage, the researchers conducted a needs assessment, examined students' characteristics, and identified students' initial critical thinking and collaboration skills. During the design stage, STEM-Fun Mathematics Story Test Media, the teaching module, student worksheets, and research instruments were developed. The validation stage involved expert review of the media, learning materials, and research instruments, followed by revisions based on the validators' recommendations.

During the application stage, students first completed the critical thinking pretest. STEM-Fun Mathematics Story Test Media was then implemented in social arithmetic learning. The first meeting focused on profit and loss, whereas the second meeting focused on discounts. During the learning process, students worked in groups, used the media to solve contextual story problems, discussed their solutions, and presented the results of their group work. The teacher's implementation and students' collaboration activities were observed throughout the learning process. After the intervention, students completed the critical thinking posttest and the student response questionnaire.

The learning activities consisted of six instructional phases. Phase 1 involved conveying the learning objectives and motivating students. Phase 2 involved presenting information related to social arithmetic. Phase 3 involved organizing students into study groups and explaining the use of STEM-Fun Mathematics Story Test Media. Phase 4 involved guiding group work and learning. Phase 5 involved evaluating learning outcomes through group presentations and discussion. Phase 6 involved giving appreciation to students for their participation in the learning activities. The final stage of the research involved analyzing and interpreting the collected data.

Data Analysis

The data were analyzed according to the type of evidence collected. Teacher implementation data from the learning implementation observation sheet were analyzed descriptively by calculating the total scores and percentages obtained from observations across the learning meetings. Students' collaboration data were also analyzed descriptively using percentages for the five collaboration indicators and were compared across the two meetings to describe changes in collaborative participation.

Students' critical thinking pretest and posttest scores were analyzed using descriptive and inferential statistics. A normality test was first conducted using the Kolmogorov-Smirnov test. Because the pretest and posttest scores met the normality assumption, a paired-samples t-test was used to examine whether there was a statistically significant difference between the two measurements at a significance level of 0.05. The magnitude of the observed improvement was additionally described using normalized gain (N-gain).

The student response questionnaire was analyzed descriptively by calculating the percentage of responses across the questionnaire items. The response results were then interpreted according to the response categories used in the study. Microsoft Excel was used for descriptive percentage calculations, while SPSS was used for the statistical analyses of the critical thinking assessment.

3. FINDINGS AND DISCUSSION

a. Implementation of STEM-Fun Mathematics Story Test Media

STEM-Fun Mathematics Story Test Media was implemented in Grade VII-E of SMP PGRI 1 Surabaya in social arithmetic learning. Before the implementation, students completed a pretest to assess their initial critical thinking skills. The learning activities were subsequently conducted through contextual story problems using STEM-Fun Mathematics Story Test Media, followed by a posttest to identify changes in students' critical thinking performance. Students' collaboration and the teacher's implementation of the learning activities were also observed throughout the learning process.

Phase 1: Conveying Objectives and Motivating Students

During the first meeting, the teacher introduced the topic of profit and loss and communicated the learning objectives. To activate students' prior knowledge, the teacher connected the lesson to familiar situations involving online shopping and buying and selling activities. Trigger questions were used to encourage students to identify relationships between the contextual situation and the mathematical concepts being studied.

During the second meeting, the same instructional structure was applied to the topic of discounts. The teacher presented the learning objectives, connected the topic to everyday purchasing situations, and posed contextual questions to encourage students to examine the information presented in the problem before determining a solution.



Figure 1. Phase 1: Conveying Objectives and Motivating Students

Phase 2: Presenting Information

In Phase 2, the teacher presented the main concepts of social arithmetic required for solving the contextual problems. The explanation provided students with a conceptual foundation for understanding the relationships among quantities in profit, loss, and discount situations. The teacher also connected the mathematical concepts with practical examples before students proceeded to the collaborative problem-solving activities.



Phase 3: Organizing Students into Study Groups

After the learning objectives and relevant mathematical concepts had been introduced, students were organized into groups consisting of approximately four students. The teacher distributed the student worksheets and explained how STEM-Fun Mathematics Story Test Media should be accessed and used. Students were then directed to work collaboratively in solving the contextual social arithmetic problems presented through the media.





Figure 3.
Phase 3: Organizing Students into Study Groups and Explaining the Use of STEM-Fun Mathematics Story Test Media

Phase 4: Guiding Group Work and Learning

During Phase 4, the teacher facilitated students' group work while they interpreted the story problems, identified relevant mathematical information, selected solution strategies, and discussed their reasoning with other group members. The teacher provided guidance when groups experienced difficulties while allowing students to construct their solutions collaboratively.





Figure 5. Phase 4: Guiding Group Work and Learning

Phase 5: Evaluation

In Phase 5, the teacher informed students that the group learning activities were approaching completion and guided them to evaluate the learning outcomes. One group was invited to present the results of its discussion, while the other students were encouraged to respond to and evaluate the presented solution. This phase provided opportunities for students to communicate their mathematical reasoning, compare alternative solutions, and reflect on the results of their collaborative work.



Phase 6: Giving Appreciation

At the end of the learning activities, the teacher provided appreciation to the groups that actively participated in presenting and discussing their solutions. Appreciation was given in the form of positive reinforcement, including prizes and applause from classmates. This activity was intended to acknowledge students' participation in the collaborative learning process.



Figure 6. Phase 6: Giving Appreciation

b. Expert Validation Results

Before being implemented in the classroom, the learning materials, STEM-Fun Mathematics Story Test Media, and research instruments were evaluated by three validators consisting of two mathematics education lecturers and one mathematics teacher.

Table 2. Expert Validators

Validator	Professional Background
Validator 1	Lecturer of Mathematics Education, Universitas Muhammadiyah Surabaya
Validator 2	Lecturer of Mathematics Education, Universitas Muhammadiyah Surabaya
Validator 3	Mathematics Teacher, SMP PGRI 1 Surabaya

The validators evaluated the teaching module, media appearance, media content, pretest-posttest instrument, learning implementation observation sheet, collaboration observation sheet, and student response questionnaire. The results are presented in Table 3.

Table 3. Validation Results of Learning Materials and Research Instruments

Learning Materials/Research Instruments	V-1	V-2	V-3	Mean	Percentage (%)	Category
Teaching Module	3.69	3.46	3.62	3.59	89.74	Very Valid
STEM-Fun Mathematics Story Test Media – Appearance	3.47	3.71	3.65	3.61	90.20	Very Valid
STEM-Fun Mathematics Story Test Media – Material	3.24	3.88	3.82	3.65	91.18	Very Valid
Pretest/Posttest Sheet	3.59	3.69	3.53	3.60	90.05	Very Valid
Learning Implementation Observation Sheet	3.50	4.00	3.83	3.78	94.44	Very Valid
Collaboration Observation Sheet	3.38	3.88	3.63	3.63	90.63	Very Valid
Student Response Questionnaire	3.33	3.83	3.83	3.67	91.67	Very Valid

The validation results showed that all learning materials and research instruments obtained percentages ranging from 89.74% to 94.44% and were categorized as very valid. The learning implementation observation sheet received the highest validation percentage, whereas the teaching module obtained the lowest percentage, although it remained within the very valid category. Minor revisions suggested by the validators were incorporated before the materials and instruments were used in the main study.



Figure 7. STEM-Fun Mathematics Story Test Media for Social Arithmetic

c. Item Validity and Internal Consistency of the Critical Thinking Instrument

The pretest-posttest instrument was piloted with 34 Grade VII-G students before being administered to the participants of the main study. Item validity was examined using Product Moment correlation. Because all three items were tested with the same sample, the critical correlation value was consistently determined using \(df = N-2 = 32\) at a significance level of 0.05.

Table 4. Item Validity Analysis of the Pretest-Posttest Instrument

Item	r-calculated	r-critical (df = 32; α = .05)	p-value	Decision	Correlation Category
Question 1	0,433*	0.339	0.010	Valid	Moderate
Question 2	0,785**	0,436	0,000	Valid	High
Question 3	0,825**	0,436	0,000	Valid	Very High

All three items met the item-validity criterion because their calculated correlation coefficients exceeded the critical value of 0.339. Question 1 showed a moderate correlation, whereas Questions 2 and 3 showed high and very high correlations, respectively. Therefore, the three items were retained for use in the main study. Internal consistency was subsequently examined using Cronbach's Alpha.

Table 5. Internal Consistency of the Pretest-Posttest Instrument

Cronbach's Alpha	Number of Items
0.463	3

The three-item critical thinking instrument yielded a Cronbach's Alpha coefficient of 0.463. This value indicates low internal consistency and therefore should not be interpreted as evidence of adequate reliability. Because the instrument consisted of only three items, the coefficient should also be interpreted cautiously. Accordingly, the relatively low internal consistency is acknowledged as a measurement limitation and should be considered when interpreting the pretest-posttest findings.

d. Teacher Implementation of STEM-Fun Mathematics Story Test Media

The teacher's implementation of the learning activities was evaluated by two observers. The results are presented in Table 6.

Table 6. Teacher Implementation Observation Results

Observation Aspect	Observer 1	Observer 2
Preliminary Activities	3.00	3.00
Phase 1: Conveying Objectives and Motivating Students	3.38	3.50
Phase 2: Presenting Information	3.75	4.00
Phase 3: Organizing Students into Study Groups	3.75	3.75
Phase 4: Guiding Group Work and Learning	4.00	4.00
Phase 5: Evaluation	3.25	3.50
Phase 6: Giving Appreciation	3.75	3.75
Teacher Assessment	3.70	3.70
Total Score	81.50	83.00

The average observer score was 82.25, corresponding to an overall implementation percentage of 85.68%, which was categorized as very good. The results indicate that the teacher was able to implement the major instructional phases, including contextual problem introduction, group organization, collaborative problem solving, evaluation, and appreciation.

An operational issue was identified in the activity related to sharing the learning-media link. The teacher did not directly distribute the link because students accessed the media through a QR code

provided in the worksheet. Therefore, future implementation guidelines should clearly specify QR-code access as one of the procedures for providing students with access to the media.

e. Students' Collaboration Skills

Students' collaboration was observed during the two learning meetings through five indicators: active contribution, productive work, compromise and flexibility, responsibility, and respect for other group members.

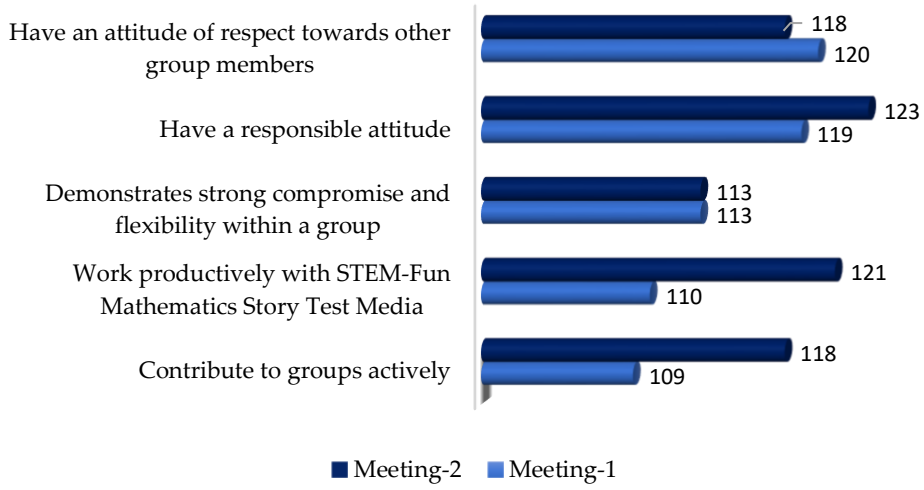


Figure 8. Students' Collaboration Activities

During the first meeting, the average percentage of students' collaboration activities was 81%, categorized as very good. Respect for other group members and responsibility were among the most frequently observed behaviors, with scores of 120 and 119, respectively. Active contribution to the group received the lowest score, at 109. This finding indicates that although students were generally able to work collaboratively, some students still required encouragement to contribute actively to constructing group solutions.

During the second meeting, the average collaboration percentage increased to **93%**, also categorized as very good. Responsibility and productive group work were among the most frequently observed collaborative behaviors, with scores of 123 and 121, respectively. The increase from 81% to 93% represents a difference of 12 percentage points, or approximately 14.8% relative to the first-meeting percentage. The higher percentage observed during the second meeting indicates stronger collaborative participation as students became more familiar with the group-based learning procedures. However, because the same observation procedure was not conducted before the intervention, this finding should be interpreted as a change in collaboration across the two implementation meetings rather than as definitive evidence of a causal effect of the media.

f. Students' Critical Thinking Skills

Students' critical thinking performance was examined by comparing their pretest and posttest scores. Before conducting the paired-samples t-test, the distribution of the scores was examined using the Kolmogorov-Smirnov normality test.

Table 7. Normality Test of Pretest and Posttest Scores

Statistic	Pretest	Posttest
N	32	32
Mean	12.0312	74.9375
Standard Deviation	11.21486	10.67085
Kolmogorov-Smirnov Z	0.971	0.660
Asymp. Sig. (2-tailed)	0.303	0.777

The normality analysis showed significance values of 0.303 for the pretest and 0.777 for the posttest. Because both values exceeded 0.05, the score distributions were considered to satisfy the normality assumption. A paired-samples t-test was therefore conducted.

The hypotheses were formulated as follows:

H_0 : There is no statistically significant difference between students' pretest and posttest critical thinking scores.

H_1 : There is a statistically significant difference between students' pretest and posttest critical thinking scores.

Table 8. Paired-Samples t-Test of Pretest and Posttest Scores

Comparison	Mean Difference	SD	SE	95% CI Lower	95% CI Upper	t	df	p
Posttest – Pretest	62.906	12.99965	2.29804	58.21938	67.59312	27.374	31	0.000

The mean critical thinking score increased from 12.03 on the pretest to 74.94 on the posttest. The paired-samples t-test indicated a statistically significant difference between the two measurements, \(t(31)=27.374, p<0.001\). Therefore, H_0 was rejected. These results show that the participating students obtained significantly higher critical thinking scores after the implementation of STEM-Fun Mathematics Story Test Media than before the implementation. However, given the absence of a comparison group, the statistically significant difference should be interpreted as an observed within-group change rather than as definitive evidence that the intervention alone caused the improvement. The magnitude of the observed change was additionally examined using normalized gain.

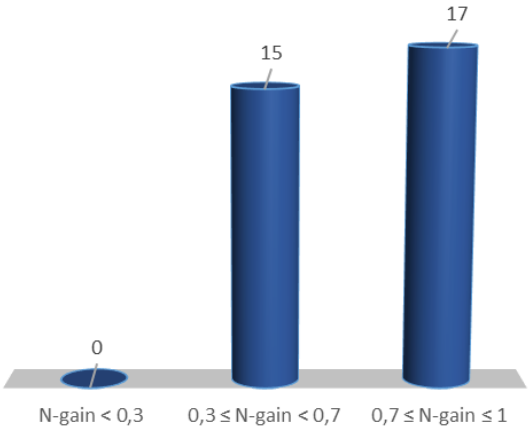


Figure 9. N-gain of Students' Critical Thinking Scores

The N-gain analysis showed that 17 students were classified in the high-gain category and 15 students in the medium-gain category. The overall N-gain score was 0.714, categorized as high. This result indicates a substantial increase in critical thinking scores within the participating group between the pretest and posttest measurements.

g. Students' Responses to STEM-Fun Mathematics Story Test Media

Students' responses were collected from all 32 participants using a seven-item questionnaire with four response options: Strongly Agree, Agree, Disagree, and Strongly Disagree.

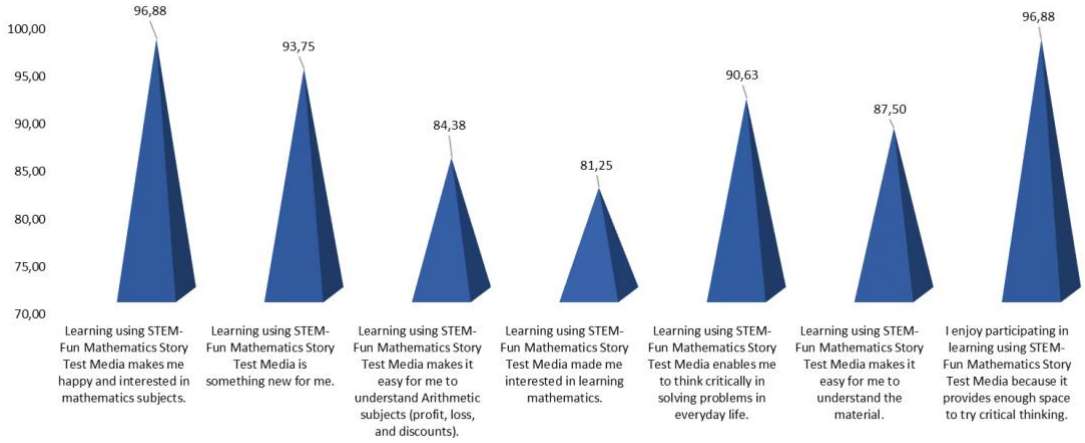


Figure 10. Students' Responses to STEM-Fun Mathematics Story Test Media

The overall positive response percentage was 90.18%, which was categorized as very positive. The result indicates that students generally responded favorably to the use of STEM-Fun Mathematics Story Test Media during social arithmetic learning.

Discussion

The findings of this study indicate that STEM-Fun Mathematics Story Test Media provided a learning environment in which critical thinking and collaboration could be addressed within the same mathematical activity. This interpretation is consistent with the broader development of STEM education, which increasingly emphasizes the integration of disciplinary knowledge, authentic problem solving, and higher-order competencies rather than the acquisition of isolated content knowledge (Gao et al., 2020; Li, 2020). A meta-analysis focusing on Asian educational contexts also showed that STEM enactment has positive associations with learning achievement, motivation, and particularly higher-order thinking outcomes (Wahono et al., 2020). Therefore, the positive changes observed in the present study can be understood within a broader pedagogical framework in which STEM activities engage students in interpreting, connecting, applying, and evaluating knowledge across contextual situations.

A central characteristic of STEM-Fun Mathematics Story Test Media is the use of contextual story problems involving social arithmetic situations such as profit, loss, discounts, and online shopping. This feature is pedagogically important because solving mathematical story problems requires more than computational proficiency. Students must comprehend the situation represented in the text, determine relevant and irrelevant information, identify quantitative relationships, translate the situation into mathematical representations, perform calculations, and interpret the results within the original context. Pongsakdi et al. (2020) demonstrated that mathematical word-problem performance is closely associated with text comprehension and arithmetic competence, indicating that story problems place simultaneous demands on linguistic interpretation and mathematical reasoning. Similarly, Gabler & Ufer (2021) showed that students' success with arithmetic situations depends on their ability to flexibly restructure and interpret the relationships represented in word problems. Thus, the story format used in this study may have created opportunities for students to engage in interpretation and analysis before carrying out numerical procedures.

The contextual nature of the tasks also connects the present study with research on mathematical modelling and authentic problem solving. Real-world mathematical tasks require students to move

between the situation and the mathematical domain by understanding the context, simplifying relevant information, mathematising relationships, working mathematically, interpreting results, and evaluating their plausibility. Cevikbas et al. (2022) emphasized that these processes constitute important components of mathematical modelling competence, while Durandt et al. (2022) demonstrated that instructional designs that provide students with greater opportunities for independent reasoning can foster modelling competency. Hartmann et al. (2021) further showed that real-world situations can stimulate students to formulate and solve mathematical problems rather than merely execute predetermined procedures. Lu & Kaiser (2022) similarly argued that open real-world modelling situations create cognitive demands that can stimulate flexible and creative mathematical thinking. From this perspective, contextual story elements in STEM-Fun Mathematics Story Test Media may function not simply as attractive packaging, but as cognitive triggers that require students to construct mathematical meaning from situations.

This mechanism helps explain the substantial difference between students' pretest and posttest critical thinking scores. During the learning activities, students were expected to identify what was known and required in a problem, analyze relationships between quantities, choose appropriate mathematical procedures, and evaluate whether the resulting solution was consistent with the contextual situation. These activities correspond to important dimensions of critical thinking, particularly interpretation, analysis, inference, and evaluation. The finding is consistent with Ilyas et al. (2022) who reported improvement in students' critical thinking performance after STEM-oriented mathematics learning. More broadly, the evidence synthesized by Wahono et al. (2020) suggests that STEM enactment is particularly promising for higher-order thinking, supporting the interpretation that the observed improvement in the present study may be pedagogically related to the problem-solving demands embedded within STEM-oriented contextual activities.

Nevertheless, the role of technology should not be interpreted as automatically producing better learning. Instead, its contribution appears to depend on how digital tools are integrated with meaningful mathematical activities. Hillmayr et al. (2020) in a meta-analysis of secondary mathematics and science learning, found positive effects of digital tools but also showed that instructional conditions and teacher support substantially influence their effectiveness. Deng et al. (2020) similarly found that digital game-based mathematics learning can increase engagement, while emphasizing the importance of instructional strategies that make students' mathematical thinking visible. Wang (2022) through a meta-analysis of digital game-based STEM education, also identified a positive overall effect on learning achievement. These findings suggest that the value of STEM-Fun Mathematics Story Test Media lies not solely in its digital form but in the interaction among digital representation, contextual problems, teacher guidance, and opportunities for students to articulate mathematical reasoning.

The present findings also underline the importance of the teacher's role in orchestrating technology-supported learning. The teacher did not merely provide access to the media but introduced contextual problems, posed trigger questions, organized students into groups, monitored their work, facilitated presentations, and guided evaluation. Research on mathematics classrooms demonstrates that effective use of digital tools depends on how teachers coordinate technological, mathematical, and social dimensions of learning. Schwarz et al. (2021) for example, showed that teachers' ability to recognize critical moments in concurrently collaborating mathematics groups can support the orchestration of collective knowledge construction. Hwang et al. (2021) likewise demonstrated that socially regulated technology-supported mathematics learning can foster more productive learning behaviors than technology use without comparable social regulation. Therefore, the high teacher-implementation score in the present study should be interpreted as an important component of the learning environment rather than as a separate administrative indicator.

The collaborative structure of the learning activities may also explain the development observed between the first and second meetings. Students did not solve the contextual problems only as individuals; they worked in small groups in which they were expected to contribute ideas, listen to peers, compare strategies, negotiate solutions, assume responsibility, and present collective reasoning. Contemporary research in mathematics education conceptualizes collaboration as a process of jointly

constructing a problem space rather than merely placing students in the same group. Pruner & Liljedahl (2021) showed that collaborative mathematical problem solving involves students actively seeking, sharing, and negotiating resources when existing individual or collective resources are insufficient. Salminen-Saari et al. (2021) further demonstrated that collaborative mathematical problem solving involves cycles of understanding, planning, implementing, watching, listening, and verifying, particularly when students develop shared attention to representations and solutions.

This interpretation is particularly relevant to the change in collaboration from 81% at the first meeting to 93% at the second meeting. The improvement may reflect students' increasing familiarity with the norms of collaborative problem solving. At the beginning of the intervention, some students may still have approached mathematical tasks as individual activities performed within a group setting. Repeated opportunities to communicate solutions and respond to peers may gradually have encouraged more active contribution, productive participation, responsibility, and flexibility. Borssoi et al. (2021) found that mathematical modelling conducted collaboratively generates interaction, negotiation, and opportunities for students to understand and simplify problem situations together. Erath (2021) similarly demonstrated that carefully designed group work can support collective mathematical knowledge construction through students' language and interaction. These studies reinforce the distinction between simply working in groups and engaging in genuine collaborative mathematical reasoning.

Technology may strengthen this collaborative process when it provides students with shared objects around which discussion can be organized. Birgin & Acar (2022) reported positive outcomes from computer-supported collaborative mathematics learning using GeoGebra, illustrating how digital representations can become common resources for mathematical discussion. Laakso et al. (2021) similarly found that collaborative digital-design activities encouraged sustained peer support and knowledge sharing. Although STEM-Fun Mathematics Story Test Media differs from these technologies, the underlying pedagogical mechanism is comparable: digital resources can function as common reference points that allow students to inspect information, exchange interpretations, and jointly develop solutions.

The relationship between critical thinking and collaboration is therefore particularly important. These competencies should not necessarily be understood as independent outcomes. In collaborative mathematical problem solving, explaining a proposed solution requires students to make their reasoning explicit. When peers question that reasoning, propose alternative procedures, or identify inconsistencies, students must evaluate evidence and reconsider their initial ideas. Critical thinking can therefore be socially stimulated through disagreement, explanation, justification, and negotiation. Kocak et al. (2021) found significant relationships among cooperativity, critical thinking, communication, and problem solving, supporting the view that these 21st-century competencies operate as interconnected rather than isolated skills. Carbonneau et al. (2020) also showed that collaboration can alter mathematical problem-solving processes and perseverance, indicating that social participation may influence the ways learners engage cognitively with challenging mathematical activities.

From this perspective, STEM-Fun Mathematics Story Test Media may support a cyclical relationship between critical thinking and collaboration. A student initially interprets the contextual information and proposes a strategy; peers then examine that strategy, ask questions, or propose alternatives; the group subsequently evaluates the competing approaches and revises its solution. Such interaction transforms individual reasoning into a collective process of justification and refinement. This explanation is consistent with current perspectives on mathematical modelling, where students are expected to interpret real-world information, construct mathematical representations, communicate results, and evaluate solutions (Cevikbas et al., 2022; Durandt et al., 2022). It is also consistent with (Spooner, 2024) who found that mathematical modelling can encourage active involvement and greater openness toward alternative ways of interpreting and approaching mathematical situations.

The positive student responses observed in this study may also be interpreted through the interaction between contextual relevance, digital presentation, and active participation. The overall

response percentage suggests that students generally accepted and engaged positively with the learning experience. Digital STEM environments can provide more interactive learning experiences when the technology is connected to pedagogically meaningful tasks rather than used merely as a presentation device. Wang (2022) found that digital game-based STEM environments can generate meaningful learning gains, while Xu & Ouyang (2022) emphasized that educational technologies in STEM must be integrated with appropriate instructional elements and learning environments to produce educational value. This distinction is important: positive student perceptions in the present study should not be attributed simply to the novelty of technology but to the combination of digital media, contextual mathematical problems, collaborative participation, and teacher facilitation.

At the same time, the results should not be interpreted as evidence that technology, story problems, or STEM integration will automatically lead to critical thinking and collaboration. Gao et al. (2020) noted that assessment practices in interdisciplinary STEM education do not always align adequately with the multidimensional competencies that interventions claim to develop. This issue is especially relevant to the present research because critical thinking was assessed using only three items. Consequently, although the significant pretest-posttest difference and high N-gain indicate substantial within-group change, the low internal consistency of the critical thinking instrument requires cautious interpretation. Future assessment should include a larger and more representative set of tasks covering interpretation, analysis, inference, evaluation, explanation, and self-regulation.

The one-group design also limits causal interpretation. The improvement in students' critical thinking scores cannot be attributed exclusively to STEM-Fun Mathematics Story Test Media because the study did not include a comparison group. Similarly, collaboration was observed only across two implementation meetings, so the change from 81% to 93% should be viewed as short-term development in collaborative participation rather than evidence of sustained growth. Future research should compare STEM-Fun Mathematics Story Test Media with alternative learning conditions, extend the intervention across multiple mathematical topics, and investigate how students' reasoning and group interaction evolve over time. Recent research on authentic mathematical modelling suggests that learning designs involving sustained engagement with real-world problems can provide valuable opportunities for developing mathematical competencies and active participation (Lu & Kaiser, 2022; Spooner, 2024). Such longitudinal and comparative designs would provide stronger evidence regarding the contribution of story-based digital STEM learning to critical thinking and collaboration.

4. CONCLUSION

This study showed that STEM-Fun Mathematics Story Test Media was implemented well in social arithmetic learning through contextual problems, group work, evaluation, and teacher guidance. Students showed higher critical thinking scores after the implementation and stronger collaboration across the learning meetings. Students also responded positively to the learning activities. These findings indicate that integrating contextual story problems, STEM-based digital media, and collaborative activities can support students' mathematical reasoning and participation. However, the results should be interpreted cautiously because the study involved only one class, had no comparison group, and used a three-item critical thinking instrument with low internal consistency. Future studies should involve larger samples, comparison groups, longer implementation periods, and more comprehensive assessment instruments. For teachers, the media can be used as an alternative to support contextual, interactive, and collaborative mathematics learning.

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