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DEVELOPMENT OF STEM-COLLABORATIVE LEARNING BASED ARITHMETIC SEQUENCES AND SERIES TEACHING MATERIAL FOR ENHANCING STUDENTS' CRITICAL THINKING

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ABSTRACT

The online learning methods used during the pandemic have impacted students' ability to communicate, collaborate, and build interpersonal relationships, which are crucial for developing collaborative skills. Students face limitations in receiving feedback and direct guidance from classmates and teachers, which affect the development of their collaborative skills. This research aims to develop STEM-Collaborative based teaching materials for arithmetic sequences and series learning that can enhance students' critical thinking abilities. Research and development (R&D) approach was employed in this study using the 4-D development model. The research population consisted of 10th-grade students in a Vocational High School in the Bondowoso region. The research sample was selected using cluster random sampling technique, including individual trials, small group trials, and field test. Data was collected through expert validation sheets, questionnaires, and students' critical thinking ability tests. The research produced products in the form of Student Worksheets, Lesson Plans, and STEM-Collaborative Learning-based Assessment of Critical Thinking. The results showed that the developed instructional materials were valid based on expert evaluations. According to student assessments, the developed instructional materials were highly practical with a score percentage of 86%. The test results demonstrated a high improvement in students' critical thinking (*n-gain* = 0,703). There was a significant difference in students' critical thinking abilities between the experimental group and the control group ($p < 0,05$). Therefore, the developed instructional materials can be considered effective in fostering students' critical thinking. The implementation of STEM-Collaborative learning from these teaching materials has provided a positive contribution to enhancing students' critical thinking skills.

Keywords: Collaborative learning, critical thinking, development, STEM, teaching material.

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INTRODUCTION

The development of technology and information continues to advance and is influenced by changes in the learning process caused by the COVID-19 pandemic. As a result, there has been a significant change in the interaction process between teachers and students (Oliveira et al., 2021). Previously, online methods replaced face-to-face learning activities. However, this method has affected students' ability to communicate, collaborate, and build important interpersonal relationships in developing collaborative skills (Umar & Ko, 2022). In line with this, Guncaga et al. (2022) states that in online learning, students experience limitations in receiving feedback and direct guidance from classmates and teachers. Valuable feedback and guidance in developing collaborative skills can be limited, which can affect students' progress and growth in collaborative aspects.

Currently, the COVID-19 pandemic in Indonesia has ended. The pandemic status in Indonesia has been lifted and replaced with an endemic status by the president. Learning in schools has been shifted back to face-to-face learning. The collaborative aspect of students can be rebuilt through collaborative learning models (Birgin & Acar, 2020). In collaborative learning, students have the opportunity to share ideas, engage in discussions, and listen to their classmates' opinions. This encourages students to think critically about the topics being discussed. Through discussion and idea exchange, students are prompted to consider different perspectives, analyze arguments, and make decisions based on critical thinking (Darmawansah et al., 2022). On the other hand, collaborative learning often involves problem-solving in groups (Anitha & Kavitha, 2022). Therefore, students can collaborate to identify problems, formulate strategies, and find effective solutions in the learning process. This process encourages students to think critically in solving problems, identify alternative solutions, and consider the consequences of each choice.

Critical thinking is a process of reasoning in a logical and reflective manner, emphasizing decision-making about what to believe or do (Ridwan et al., 2022). Through critical thinking, individuals can solve problems, make decisions, or satisfy their curiosity by working collaboratively through collaboration and communication. Therefore, the goal of critical thinking is to steer individuals away from erroneous decisions and hasty decision-making. Critical thinking skills support success in various fields of study, including mathematics education (Evendi et al., 2022). Thus, critical thinking skills are essential for students in the process of learning mathematics.

The results of several studies show that the level of students' critical thinking skills is still low, especially in the context of Higher Order Thinking Skills (HOTS) mathematics problem solving (Kharisma, 2018; Purwanto et al., 2020; Sartika & Alyani, 2023). This finding is supported by Turmuzi et al. (2022), who state that the context of HOTS problems and their connection to the required solutions are generally difficult for students to understand. Students often face difficulties in solving HOTS problems related to arithmetic sequences (Qolbi et al., 2022). These difficulties arise because students still struggle to differentiate between problem-solving tasks and story-based questions. On the other hand, based on field observations, the low level of students' critical thinking skills is attributed to the teaching methods employed by teachers, which are often heavily reliant on lecturing. Efforts to develop students' critical thinking skills in mathematics have become a primary agenda in mathematics education curricula worldwide

(Umam & Susandi, 2022). Therefore, it is necessary to implement a learning approach that can enhance students' critical thinking skills.

One effective approach to enhancing critical thinking skills is the STEM framework, known as an innovative applied learning approach that incorporates interdisciplinary connections (Hiğde & Aktamış, 2022; Mater et al., 2020). In our opinion, the STEM approach, particularly in the context of mathematics education, plays a vital role. This approach is based on the integration of various fields, including Science, Technology, Engineering, and Mathematics. Almost all researchers agree that STEM education is a modern educational phenomenon aimed at enhancing students' understanding of disciplinary knowledge within the engineering design cycle of the curriculum (Wang et al., 2022). Through this approach, students are trained to apply the knowledge they acquire more effectively in solving tasks and problems relevant to the professional world (Putri & Juandi, 2023). By adopting the STEM approach in learning, students are given opportunities to engage in hands-on activities, collaborative projects, and real-life problem-solving (Hiğde & Aktamış, 2022). They are encouraged to integrate knowledge from various disciplines to develop a more comprehensive understanding and enhance their critical thinking skills.

The STEM framework of can be implemented through collaborative learning (Hadiyanti et al., 2021). In STEM learning activities, learners are often faced with problems that do not have a single solution (Lin et al., 2023). Therefore, the interaction and arrangement between teams and individuals are crucial in STEM activities, especially considering learners' motivation, emotions, cognitive abilities, and metacognitive skills (Hu & Guo, 2021). Collaborative learning emphasizes the importance of learning interactions, enabling students to gain knowledge from each other through collaboration, solving problems together, generating new concepts, and sharing information (Hadiyanti et al., 2021). When students work collaboratively, they are exposed to different perspectives, critical thinking, and in-depth analysis (Sundararajan et al., 2018). Experiences or learning through solving real-world problems promote the development of students' critical thinking skills, such as analyzing information, evaluating alternatives, and making sound decisions (Shanta, 2022). Active exchange of ideas within small groups not only captures students' attention but also promotes critical thinking. Collaboration provides opportunities for students to engage in discussions, take ownership of their learning, and become critical thinkers (Agbi & Yuangsoi, 2022). Additionally, collaborative learning allows students to learn together in heterogeneous groups, supporting, observing, criticizing, or sharing perspectives with one another, and ultimately sharing their achievements (Le et al., 2018). Several studies have demonstrated successful cases of collaborative learning to facilitate a more comprehensive knowledge construction process for students. Wang et al. (2020) examined student interactions and differences in cognitive load during online collaborative discussions using various forms of learning materials. Sisman et al. (2022) investigated the learning behavior patterns of students with different academic achievements in direct collaborative group activities and identified significant relationships between teacher guidance and intervention and students' knowledge construction behaviors.

Based on the background issues mentioned above, the objective of this research is to develop STEM-Collaborative Learning-based instructional materials. In this study, the developed instructional product includes student worksheets, lesson plans, and assessments of critical

thinking skills in arithmetic sequences and series that are valid and practical. The instructional materials developed aim to enhance students' critical thinking. Furthermore, the development of these instructional materials is expected to contribute to the advancement of innovative mathematics teaching approaches.

METHODS

Research and Development (R&D) is used for this development. The development model employed in this study is the 4-D model developed by Thiagarajan. The 4-D development model consists of four stages: Define, Design, Develop, and Disseminate (Khasanah & Nurnugroho, 2021). Therefore, the development procedure in this study consists of four stages: 1) identification stage which includes student analysis, task analysis, specification of learning outcomes, and content analysis, 2) design stage which involves designing student worksheets, lesson plans, and assessments of critical thinking skills in arithmetic sequences and series, 3) development stage which includes expert validation, small group trials, and field tests and 4) The final stage or dissemination is carried out by distributing the product to colleagues so that it is used (adopted) to be applied in other classes and presented in conference.

The population of this study consists of all 10th-grade students in one Vocational High School in the Bondowoso region. The research sample was selected using a random cluster sampling technique, with 4 students chosen for the individual test, a small group trial involving small groups, and a field test involving a larger sample size. In the field test, 36 students were assigned to the experimental group, while the other 36 students formed the control group. This study involves two variables, namely the dependent variable and the independent variable. The dependent variable in this study is students' critical thinking skills, while the independent variable is the use of STEM-Collaborative Learning-based instructional materials.

Data collection in this study involves expert validation sheets, questionnaires, and tests for assessing critical thinking skills. The expert validation sheets are used during the development phase and are filled out by validators, including mathematics experts, language and instructional design experts, media and graphic design experts, as well as mathematics teaching practitioners. The experts provide scores ranging from 1 to 5 for each measured aspect. The student response questionnaires are given at the end of the learning process using a scale of 1 to 5. The scores from both the expert validation sheets and student response questionnaires will be processed separately to assess validity and practicality. The scores for validity and practicality will then be analyzed and compared to the criteria indicated in Table 1.

Table 1. Criteria for Validity/Practicality.

Score (%)	Criteria
86 – 100	Very Valid/Practical
71 – 85	Valid/Practical
36 – 70	Less Valid/Practical
0 – 35	Invalid/Not Practical

modificated from Masamah et al. (2023).

The assessment of critical thinking consists of two essay test questions, namely the pretest and posttest. The competency indicators for critical thinking skills are adopted from Basri

et al. (2019), which include six indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The chosen subject matter for assessing critical thinking skills is arithmetic sequences and series. The data obtained from the assessment will be analyzed using univariate t-test to examine the statistical differences. Additionally, N-Gain analysis will be employed to compare the differences in scores between the beginning and end of the learning process in the experimental and control groups (Nikmah et al., 2021). The N-Gain score is categorized as presented in Table 2 (Mandala & Setyaningrum, 2024). This analysis aims to assess the effectiveness of the developed teaching materials in terms of improving students' critical thinking skills.

Table 2. Value category of N-Gain score.

N-gain Score	Category
N-gain ≥ 0.70	High
$0.30 <$ N-gain < 0.70	Medium
N-gain ≤ 0.30	Low

RESULT AND DISCUSSION

The Defining Stage is the initial stage that involves analyzing needs. The goal of the defining stage is to establish and define the learning needs by analyzing the objectives and limitations of the instructional material used in the development of teaching materials. Student analysis is conducted to gain a deep understanding of students' characteristics and needs. The characteristics include students' cognitive development, mathematical abilities, and their experience in group learning. The results of the analysis of students' critical thinking profiles from several literatures show that there are still many students who have low critical thinking abilities (Alifia et al., 2019; Martiani & Juandi, 2019; Miatun & Khusna, 2020; Purwanto et al., 2020; Alvariz & Miatun, 2023). This can be attributed to the students' lack of active participation in asking questions and engaging in discussions with their peers. In addition, based on observation results students' hesitancy to ask questions may be due to feelings of shame, lack of self-confidence, or a sense of reluctance and resignation because they have labeled themselves as unable to understand arithmetic sequences and series materials. In the analysis of the content and tasks, the formulation of indicators is based on two criteria for competency achievement that are aligned with the independent curriculum. These criteria are analyzing arithmetic sequences and series, and solving contextual problems related to arithmetic sequences and series that are connected to STEM-Collaborative Learning. The learning achievement specifications must include critical thinking skills as the main objective to be achieved. Critical thinking skills encompass students' abilities to interpret, analyze, evaluate, and connect information, as well as their ability to solve problems and make decisions based on logical and rational thinking.

The next stage is the design stage, where the researcher develops the design format of the student worksheets along with their initial layout, the lesson plan design format, and the design of the assessment instrument for critical thinking skills in arithmetic sequences and series. These teaching materials are designed using the STEM approach with Collaborative Learning model. The adoption of instructional syntax, originally based on Nikiforos and Kolyvas

(2020) and Worsham et al. (2021), was subsequently modified by the researcher to develop the STEM-Collaborative Learning syntax consisting of 6 stages. The first stage is the introduction stage, where the STEM (Science, Technology, Engineering, Mathematics) concepts are introduced to students as the main foundation of learning. The learning objectives are explained and connected to real-world relevance. The second stage is the formation of groups, where students are divided into working groups consisting of several students with diverse group compositions. This aims to encourage collaboration and mutual learning among students. The third stage involves determining the collaborative project, where the collaborative project is tailored to the arithmetic sequences and series topic and the STEM context is defined as the focus of learning. In this stage, the teacher poses questions or challenges to the students to encourage problem-solving and the application of arithmetic sequences and series concepts in the project. The fourth stage is the investigation and problem-solving stage. In this stage, students work collaboratively in their groups to carry out the project. Interactions, discussions, and mutual assistance are activated to solve problems and apply arithmetic sequences and series concepts. The fifth stage is the presentation and discussion stage. The project results from each group are presented to the class, followed by collective discussions and reflections. The purpose of this presentation and discussion is to understand the thinking process and solutions generated by each group. The final stage is the evaluation and feedback stage. Evaluation is conducted on the group's performance and students' understanding of the applied arithmetic sequences and series concepts. Positive and constructive feedback is provided to each group to improve future learning experiences.

The next stage is the development of teaching materials. In this stage, the researcher realizes the initial design of the products that have been previously planned. The process of creating teaching materials such as Student Worksheet, lesson plan, and assessment of critical thinking skills in arithmetic sequences and series is carried out in accordance with the developed concept. The creation of Student Worksheet and lesson plan is tailored to the needs, which means the design format of the Student Worksheet and lesson plan includes steps for STEM-Collaborative Learning-based instruction that supports students' critical thinking skills. An illustration of the front cover of the Student Worksheet can be seen in Figure 1. Then, last stage is the dissemination stage involves distributing the learning materials to the tenth-grade teachers at SMKN 2 Bondowoso and presenting them at the ICOMELA 2023 Conference.

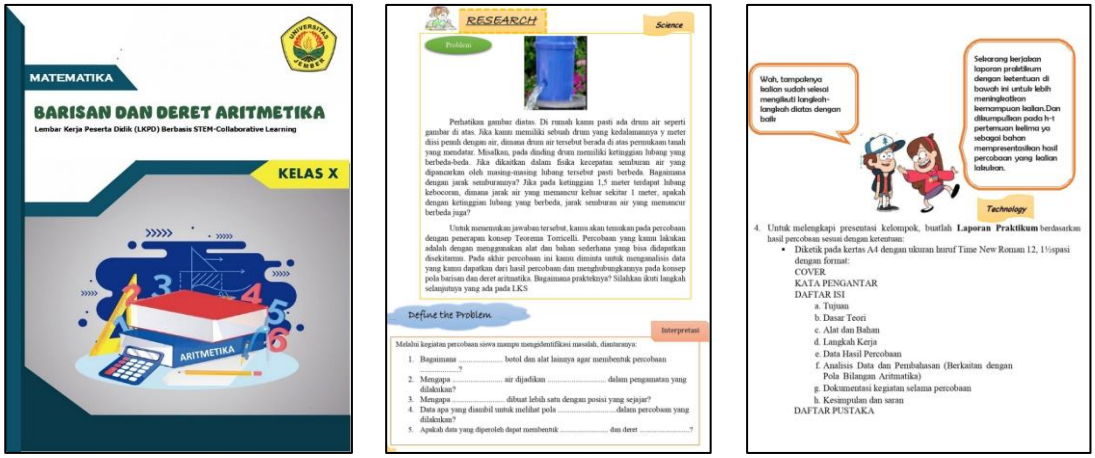

Figure 1. Samples of worksheets display.

The developed teaching materials were then tested for their validity through expert judgment assessment. The results of the validity calculation for the developed teaching materials are presented in Table 3.

Table 3. The validity of the STEM-Collaborative Learning-based teaching material.

Product	Assessed Aspect	Score (%)	Criteria
Student Worksheet	Material expert	91	Very Valid
	Design expert	74	Valid
	Learning expert	91	Very Valid
Lesson Plan	Material expert	96	Very Valid
	Learning expert	92	Very Valid
Assessment of Critical Thinking	Material expert	91	Very Valid
	Learning expert	91	Very Valid

Based on the results in Table 3, it can be concluded that the developed teaching materials meet the validity criteria based on expert opinions. Therefore, the obtained results indicate that the student worksheet, lesson plan, and the assessment of critical thinking can be used to gather data.

A small group trial was conducted to gather feedback, identify potential issues, and make improvements before involving a larger population or implementing the innovation as a whole. The trial was conducted to assist in testing the reliability of the Assessment of Critical Thinking instrument used, as well as to refine and identify any weaknesses or shortcomings that needed to be addressed before proceeding to the next stage. The total number of the Assessment of Critical Thinking is 4 (Cronbach's alpha = 0,97).

The main purpose of field tests is for valuable data and experiences to be gathered on how a product or system functions in real-life situations. Field tests were conducted to assess the practicality and effectiveness of the developed instructional materials in terms of students' critical thinking abilities. The implementation of learning during field trials in the experimental class is depicted as shown in Figure 2.

Figure 2. Field tests conducted on 10th-grade vocational high school students.

This implementation examined the practicality of the teaching materials based on student assessments. The assessment focused on the Student feedbacks. Questionnaires were given to 36 students in the experimental class. Based on the analysis of the questionnaire results, the average score for the assessment of the student worksheets was 43 out of a maximum score of 50. This indicates that the Student Worksheets achieved a percentage of 86%, which falls within

the category of highly practical. Therefore, according to student assessments, the developed teaching materials are considered practical. In addition to assessing practicality, the implementation also aims to review the effectiveness of the developed teaching materials.

Table 4. Mean, standard deviation (SD) and n-gain of students' critical thinking.

Data	*N*	Min	Max	Mean	SD	n-gain
Pretest	36	23	54	35.64	8.874	0.703
Posttes	36	57	100	80.89	9.919	

The results of the assessment on the critical thinking abilities of the experimental group showed an average score of 80,89 (see Table 4). This score indicates that the students' critical thinking abilities are at a good level. The difference between the two scores is 45,25 with an n-gain value of 0,703. This score indicates a high significant improvement in students' critical thinking abilities, as evidenced by the n-gain value (0,703 > 0,7) (Plummer et al., 2022). Furthermore, the results of the average score of each component of students' mathematical critical thinking are presented in Figure 3. The score range for each component of mathematical critical thinking is from 0 to 4. Based on this figure, the highest improvement that occurred was in the evaluation and explanation aspects.

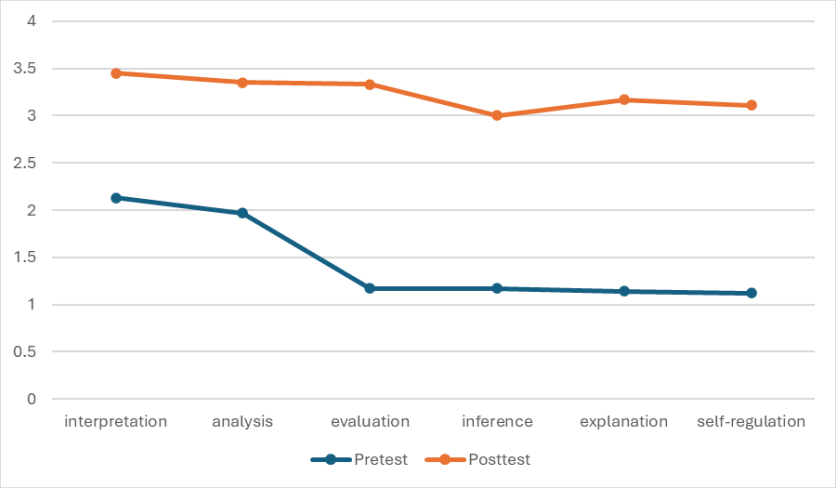

Figure 3. Comparison of pre-test and post-test average scores for each critical thinking component.

Statistical tests were conducted to examine the influence of the developed instructional materials on students' critical thinking abilities. Before conducting the tests, prerequisite tests including the normality test and homogeneity test were performed. These steps are preliminary measures taken before conducting the independent sample t-test. Based on the results of the normality test, the significance values for the experimental and control groups were 0,468 and 0,068, respectively. These results indicate that both sets of data are normally distributed (Sig. > 0,05). The homogeneity test using Levene's test yielded a result of 0,598, indicating that the critical thinking abilities of the control and experimental groups have equal variances or are homogenous (Sig. > 0,05). After conducting all the prerequisite tests, further testing was carried

out to determine the influence of the developed instructional materials on students' critical thinking abilities. The first test was performed on the pre-test results for the experimental and control groups. Based on the test results, the Sig. (2-tailed) values obtained were 0,263. The Sig. (2-tailed) value for the pre-test of the control and experimental groups under Equal Variances Assumed (due to homogenous data) is 0,263, which is greater than 0,05. Therefore, the control and experimental groups have the same level of ability. Next, an independent sample t-test was conducted on the post-test results to compare them.

Based on the output in Table 5, the significance value (2-tailed) under equal variances assumed (due to homogeneous data) is 0.000, which is less than 0.05. This indicates that there is a difference in the average learning outcomes between the control group and the experimental group. It demonstrates that the developmental research in implementing STEM-Collaborative Learning has an impact on students' critical thinking. The previously observed n-gain results also showed a significant increase in students' critical thinking abilities through the implementation of the developed teaching materials. Therefore, it can be concluded that the developed instructional materials are effective in developing students' critical thinking.

Table 5. Results of independent samples test for post-test.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Test-CT	Equal variances assumed	.062	.804	4.338	70	.000	-9.944	2.292	-14.516	-5.372
	Equal variances not assumed			4.338	69.887	.000	-9.944	2.292	-14.516	-5.372

STEM with collaborative learning is a teaching approach that combines the principles of science, technology, engineering, and mathematics with the benefits of collaborative learning. This approach can be used to teach a variety of STEM topics, and it has been shown to be effective in improving student learning outcomes. There are many benefits to using STEM with collaborative learning. First, it can help students to develop their critical thinking and problem-solving skills (Ridho et al., 2021). When students work together on a STEM project, they must learn to communicate effectively, share ideas, and compromise. This helps them to develop the skills they need to be successful in STEM careers. Second, STEM with collaborative learning can help students to develop their teamwork skills (Yegorina et al., 2021). When students work together on a project, they must learn to rely on each other and to support each other's learning. This helps them to develop the skills they need to be successful in the workplace. Third, STEM

with collaborative learning can help students to develop their creativity (Wongta et al., 2021). When students are given the opportunity to work on a STEM project, they are free to come up with their own ideas and solutions. This helps them to develop their creativity and to think outside the box.

There are many ways to implement STEM with collaborative learning. One way is to use project-based learning. In project-based learning, students are given a real-world problem to solve (Diana et al., 2021). They must then work together to come up with a solution. This is a great way to get students engaged in STEM and to help them to develop their critical thinking and problem-solving skills (Baran et al., 2021; Sumarni & Kadarwati, 2020). Another way to implement STEM with collaborative learning is to use problem-based learning. In problem-based learning, students are presented with a problem that they must solve (Adel El Sayary et al., 2015; Ariyatun & Octavianelis, 2020). They must then gather information, brainstorm solutions, and test their solutions. This is a great way to get students engaged in STEM and to help them to develop their critical thinking and problem-solving skills (Astuti et al., 2021). No matter how you choose to implement STEM with collaborative learning, it is a great way to improve student learning outcomes. This approach can help students to develop their critical thinking, problem-solving, teamwork, and creativity skills. These are all essential skills for success in STEM careers and in the workplace. STEM with collaborative learning is a powerful way to engage students in STEM and to help them to develop the skills they need to be successful in their careers (Kareem et al., 2022).

CONCLUSION

This study successfully developed STEM-Collaborative Learning based teaching materials, consisting of Student Worksheets, Lesson Plans, and Assessments of Critical Thinking. The research findings indicate that these teaching materials meet the standards of validity, practicality, and effectiveness in teaching mathematics. The specifically developed teaching materials focus on the application of arithmetic sequences and series concepts in real-world situations, emphasizing collaboration among students in problem-solving. The implementation of STEM-Collaborative Learning using the developed teaching materials positively contributes to the development of students' critical thinking skills. Through learning that involves active interaction between students and the application of real problem-solving, students can engage more actively and take an active role in arithmetic sequences and series learning. This research provides recommendations for educators and curriculum developers to consider the use of the STEM-collaborative approach in teaching arithmetic sequences and series to enhance students' critical thinking. Ongoing and future experiments should be conducted to continuously improve and refine the teaching methods and materials used in STEM education.

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