



# STEM-based approach: A learning design to improve critical thinking skills

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Critical thinking; Mathematics learning design; STEM.

## Abstract

**Background:** The STEM approach in learning integrates the concepts of science, the use of technology, engineering, and mathematics, which support enthusiastic, creative, and active learning activities by students. In this context, it is necessary to develop ways to improve the understanding of the concept of a three-variable system of linear equations in high school students.

**Aim:** The purpose of this study was to produce a learning trajectory in the three-variable linear equation system material using the STEM approach for high school students, with the main objective of increasing students' critical thinking skills.

**Method:** The method used is 'design research', which includes three stages: preliminary, teaching experiment, and retrospective analysis. The research was conducted at a public high school in Palembang City, using qualitative descriptive data analysis techniques based on observation, interviews, and tests designed to measure students' critical thinking skills.

**Result:** The results of this study are STEM-based learning trajectories that are effective in helping students understand the system of three-variable linear equations. The hypothetical learning trajectory (HLT) that has been implemented is a successful tool in helping students understand the concept and can improve students' critical thinking skills.

**Conclusion:** The STEM-based mathematics learning design produced in this study has the potential to serve as a reference for teachers in improving students' critical thinking skills, especially in the subject matter of a system of three-variable linear equations. It is hoped that this approach will become a valuable tool in helping students understand mathematical concepts in greater depth in the future.

## INTRODUCTION

Critical thinking is an intellectual process that involves the analysis, evaluation, synthesis, and reflection upon complex information or issues (Basri et al., 2019; Suryani, 2023). In the context of mathematics education, critical thinking not only enables students to understand concepts and solve problems, but it also aids them in honing their logical reasoning, situational analysis, and evaluation of arguments (Sachdeva & Eggen, 2021). This skill is a core component of mathematical literacy and is essential in preparing students to tackle challenges in an ever-changing modern world. Critical thinking has transcended the status of merely being an academic skill to become one of the most valued 21st-century skills in the professional realm. The ability to dissect problems, appraise solutions, and make informed decisions is pivotal in numerous professions and industries (Cailloux & Meinard, 2019; Falcó-Pegueroles et al., 2020;

Tomesko et al., 2022). In education, embedding critical thinking within the curriculum especially in subjects like mathematics prepares students for broader life and career success. Promoting critical thinking in math education is tantamount to investing in individuals' and communities' capacity to adapt, innovate, and thrive in an increasingly complex and interconnected world (Sachdeva & Eggen, 2021).

STEM (Science, Technology, Engineering, and Mathematics) is an interdisciplinary approach to learning that integrates these fields in real-world contexts (Dare et al., 2018; Kong & Matore, 2021). This approach bridges the gap between school education and the global workforce, fostering essential STEM literacy in an economy that is increasingly knowledge-based (Karahana et al., 2015). However, when it comes to teaching the system of linear equations involving three variables, a significant challenge lies in effectively applying this STEM approach to enhance students' conceptual understanding. Many students find it challenging to link this mathematical concept to real-world applications (Papadakis et al., 2021), and educators often encounter difficulties in designing and implementing STEM-focused teaching for this subject matter (Kong & Matore, 2021).

STEM materializes when science or math learning involves solving authentic problems within social, cultural, and functional contexts (Widana et al., 2021). Authentic learning in STEM emphasizes the use of real-world, intricate problems and solutions that are relevant to students' lives (Baskaran & Abdullah, 2021). This approach allows students to meaningfully apply their knowledge and skills, connecting their learning to real-life scenarios (Lee, 2020; Priemer et al., 2019). By integrating science, technology, engineering, and mathematics in such authentic settings, students can deepen their understanding of these subjects and their applicability in the real world. However, effective solutions to these challenges remain underdeveloped. The ways in which educators design and implement STEM integration, as well as their beliefs about how this approach can improve students' understanding, still require further research.

In previous research, it has been acknowledged that educational methodologies employing a STEM approach yield positive learning outcomes for students and offer fresh pedagogical insights for teachers (Ilyas et al., 2022). Students gain the opportunity to learn science, mathematics, and engineering by tackling problems that have real-world applications within the STEM pedagogical framework (Council, 2012; Maruf et al., 2020). Ilyas et al. (2022) further indicate that the learning trajectory spawned by the STEM approach enhances students' enthusiasm, creativity, and teamwork skills. Substantiating this, Wahono et al. (2020) and Yıldırım & Sidekli (2018) affirm that this approach can also elevate students' critical thinking abilities. However, research specifically focusing on the application of the STEM approach to critical thinking skills, particularly in the context of the system of linear equations with three variables, remains scant. While the STEM approach has proven successful in various contexts, its application to the subject of systems of linear equations involving three variables warrants additional understanding and more tailored instructional strategies. This gap accentuates the need for further research aimed at exploring and crafting effective methods for integrating the STEM approach with this intricate mathematical topic. It is this void that the current research aims to fill.

The primary objective of this research is to construct a learning trajectory in the subject matter of systems of linear equations with three variables using a STEM approach for high school students. The central aim is to enhance students' critical thinking skills.

## METHODS

### *Design*

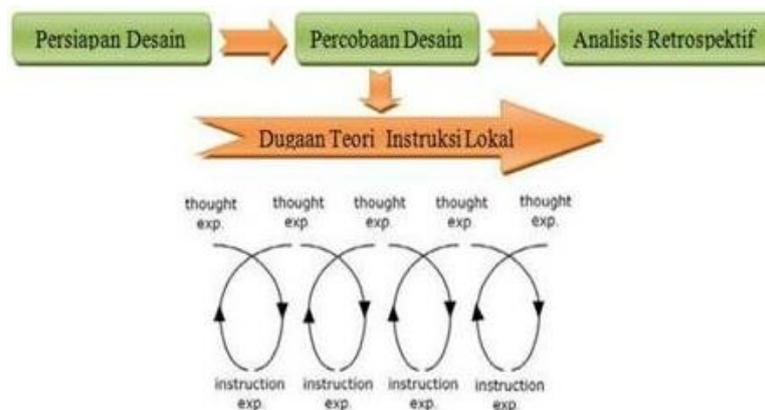
This research employs a validation-type design research methodology aimed at structuring STEM-based mathematics learning in the context of systems of linear equations with three variables. The design has dual purposes: to refine theories concerning learning processes and strategies that facilitate such learning, and to develop a Learning Instructional Trajectory (LIT) through collaboration between researchers and educators to elevate the quality of instruction (Handayani et al., 2020).

### *Participants*

The participants of this study consist of 42 Grade 10 science track students at SMA Negeri 2 Palembang. The research also involves a teacher who serves as a model for delivering the designed curriculum.

### *Instuments*

The methodology for this study employs a tripartite design research approach consisting of preliminary planning, teaching experimentation, and retrospective analysis (Lestari et al., 2021). This approach is visually outlined in the Siklik Design Research framework, shown in Figure 1. Data collection mechanisms include pre-tests, post-tests, Student Activity Sheets (SAS), multimedia documentation (comprising both video recordings and photographs), classroom observations, and participant interviews. The employed indicators for assessing critical thinking skills are interpretation, analysis, evaluation, and inference, congruent with the criteria laid out by Facione (2015).



**Figure 1.** Siklik Design Research

### *Data Analysis*

Data collection techniques encompass pre-tests, post-tests, SAS, multimedia documentation, classroom observations, and interviews. The pre-test serves as a foundational benchmark for the learning material, while the post-test is utilized to gauge the effectiveness and applicability of the SAS in enhancing student comprehension of the subject matter. During the pilot experimentation phase, the SAS is subjected to student feedback for design refinement.

Observational and interview data are collectively analyzed alongside student SAS submissions, and are subsequently aligned with the Hypothetical Learning Trajectory (HLT) to formulate the final Learning Instructional Trajectory (LIT). The critical thinking indicators, inclusive of interpretation, analysis, evaluation, and inference, are elaborated upon in Table 1.

**Tabel 1.** Indicators of Critical Thinking Skills

No	Critical Thinking Indicators
1	<i>Interpretation:</i> Understanding and articulating the meaning or intent behind mathematical statements or problems.
2	<i>Analysis:</i> Identifying the relationships among provided information, the problem to be solved, and all requisite concepts while formulating a problem-solving plan.
3	<i>Evaluation:</i> Assessing the credibility of statements and gauging the logical strength of proposed solutions or arguments.
4	<i>Inference:</i> Drawing reasonable conclusions by providing all pertinent and logical justifications.

## RESULTS AND DISCUSSION

### *Result*

#### **Preliminary Design Phase**

In this phase, interviews with teachers and classroom observations are conducted, which will be used for the second cycle. The findings from these interviews and observations contribute to the design of the Hypothetical Learning Trajectory (HLT). The HLT is formulated based on the learning objectives for the topic of three-variable linear equation systems, aligned with STEM education and focused on enhancing students' critical thinking skills.

Classroom interviews and observations aim to understand the current state of the students. Interviews with teachers are intended to grasp both the collective and individual characteristics of the students as well as identify challenges in the learning activities. Additional focal points include examining the teaching methods employed by the teacher, querying a few students about the topic of three-variable linear equation systems, and interviewing the teacher who will serve as the model for this research. The interview with the model teacher yields information about the teacher's background, classroom norms including interaction and organization, challenges faced in teaching the topic, students' level of comprehension, the teacher's experience with the STEM approach, context exploration, discussion of the HLT design created by the researcher, and clarification of the various research phases.

Each activity outlined includes the learning objectives and prior knowledge needed for said activity. Below is an overview of the Hypothetical Learning Trajectory (HLT) described as follows:



students with lower abilities were found to be less proficient in evaluating their answers. For instance, they were able to turn word problems into a system of three-variable linear equations but failed to draw conclusions from their results. These students generally completed the problems without revisiting their answers for evaluation. They were only able to analyze and identify basic elements such as the variables used. As for those with the lowest abilities, these students could merely identify the variables involved without resolving the given problems. While some critical thinking indicators were evident in a subset of students, others demonstrated only a few of these skills. Below is an example of a student's answer to question number 2:

Jawab:

$$5A + 8B + 6C = 1 \text{ menit}$$

$$60A + 80B + 90C = ?$$

$$12(5A) + 10(8B) + 15(6C) = ?$$

$$12 + 10 + 15 = 37 \text{ menit}$$

Jawab:

Kemasan A	Kemasan B	Kemasan C
$\frac{60}{5}$	$\frac{80}{8}$	$\frac{90}{6}$
= 12	+ 10	+ 15
= 37 menit.		

la membutuhkan waktu 37 menit untuk menyelesaikan tugas mengemas produk makanan tersebut.

Figure 4. Student's Answer to Question Number 2

Subsequently, the first cycle of the learning activity comprises three Student Activities. In the initial meeting, the teacher provides the students with Activity Sheet 1 (LAS 1). The teacher begins by exploring the students' prior knowledge about vacuum packaging for a local dish called 'pempek,' which they may have encountered before. Students are asked to describe what they know about vacuum packaging in the context of 'pempek' and how such vacuum systems are utilized. The teacher then informs the students of the learning objectives for the day and motivates them by pointing out that modern packaging methods are increasingly leveraging advanced technologies like vacuum sealing for greater time and energy efficiency. The details of LAS 1 from the first meeting are shown in Figure 5.

Menyusun Bentuk Sistem Persamaan Linear Tiga Variabel
Aktivitas 1

**PERMASALAHAN**

**KETAHANAN PENGEMASAN VAKUM PEMPEK**

Ternyata ada perbandingan ketahanan tiga jenis pengemasan pempek, mulai dari pempek vakum, pempek frozen dan pempek vakum frozen, dengan memahami teknik ini, anda nantinya dapat menentukan lama ketahanan pempek Palembang. Kamu dapat melihat perbandingan tersebut melalui video berikut. Selamat menonton



Seorang produsen pempek Palembang ingin mempelajari hubungan matematis antara suhu penyimpanan, waktu penyimpanan, dan tekanan vakum terhadap masa simpan pempek vakum. Mereka ingin merumuskan persamaan linear tiga variabel yang merepresentasikan hubungan ini, serta mengidentifikasi kombinasi nilai variabel yang menghasilkan masa simpan pempek vakum tertinggi. Dapatkan kalian membantu mereka dengan menjawab permasalahan berikut.

1. Scan barcode di atas, amati video pada menit 2:06. Manakah pengemasan yang memiliki masa simpan paling lama? Mengapa demikian? (Crisma)

Figure 5. Issues in Activity Sheet 1 (LAS 1)

The problems in LAS 1 are structured in a manner that incorporates critical thinking indicators along with STEM components. An example answer from a student in Group 2 is showcased in Figure 6.

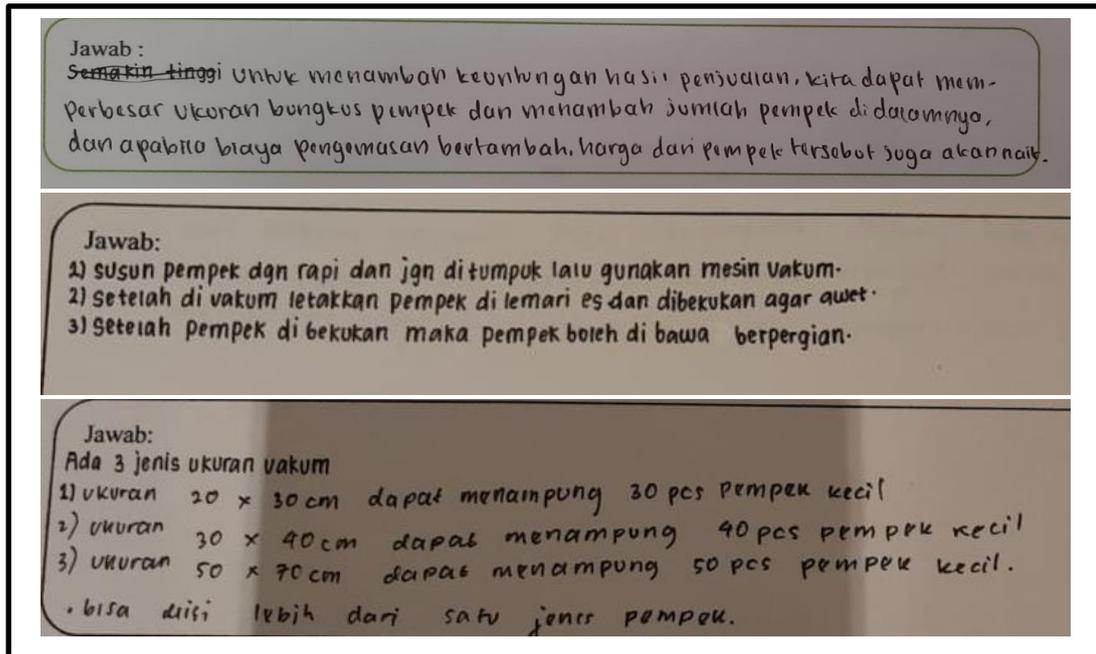


Figure 6. Response from Group 2

Based on the response from Group 2, students were able to formulate the given problem into a system of three-variable linear equations. However, in question number 4, they encountered challenges in representing the relationships between variables. Nonetheless, it is from such responses that students will eventually be guided towards framing the equations in a three-variable linear system. For the second meeting, the problems in Activity Sheet 2 (LAS 2) are displayed in Figure 7.

**PERMASALAHAN**

**Konteks: Harga paketan vakum pempek**

Andi memperhatikan bahwa harga paket vakum pempek tergantung pada tiga faktor utama: jumlah pempek, jumlah isi dalam paket, dan biaya pengemasan. Oleh karena itu, Andi ingin mencari tahu hubungan antara ketiga faktor tersebut.

Suatu toko pempek memiliki tiga jenis isi pempek: A, B, dan C. Setiap jenis isi memiliki biaya pengemasan yang berbeda. Kita juga memiliki target penjualan harian untuk masing-masing jenis isi pempek.

Diberikan informasi berikut:

- Jumlah total pempek yang akan diproduksi adalah 500.
- Target penjualan harian untuk pempek isi A adalah 200.
- Target penjualan harian untuk pempek isi B adalah 150.
- Target penjualan harian untuk pempek isi C adalah 100.
- Biaya pengemasan per pempek isi A adalah 1000 rupiah.
- Biaya pengemasan per pempek isi B adalah 800 rupiah.
- Biaya pengemasan per pempek isi C adalah 1200 rupiah.

Bantulah Andi untuk menyelidikinya

1. Bagaimana perubahan dalam jumlah pempek yang diproduksi dan jenis isi pempek yang dipilih dapat mempengaruhi hasil penjualan dan keuntungan? Tuliskan pendapatmu.

*(Science)*

Figure 7. Issues in Activity Sheet 2 (LAS 2)

Here is an example answer from a student in Group 1, as shown in Figure 8.

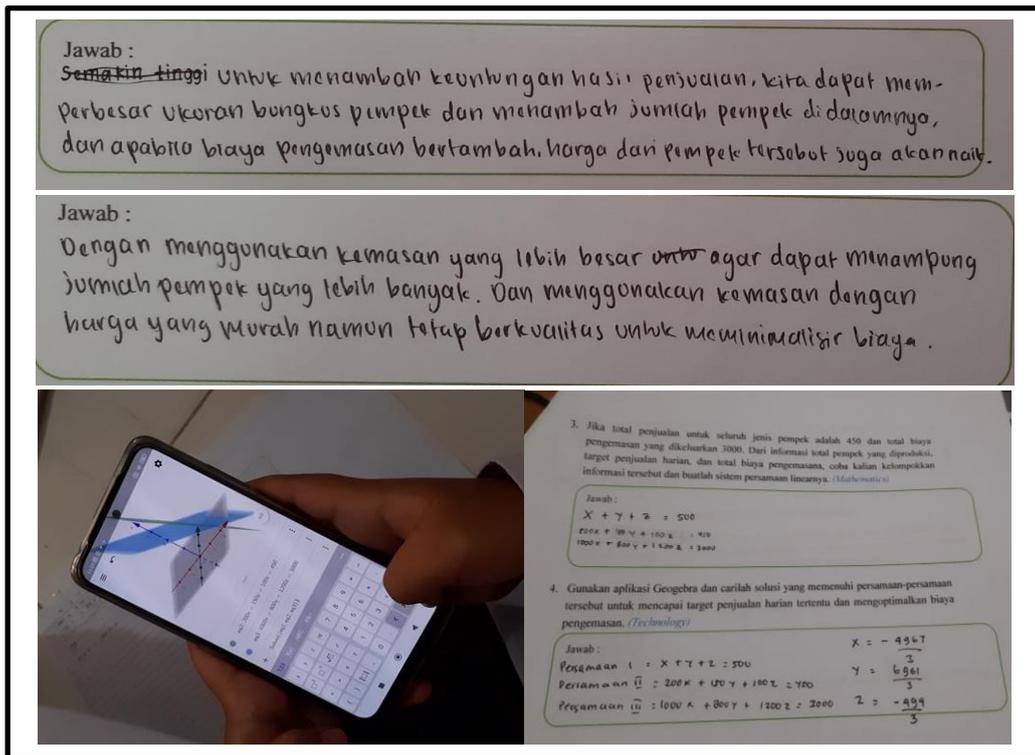


Figure 8. Response from Group 3

According to the responses from Group 3, students were able to solve the system of three-variable linear equations using graphical methods through the Geogebra application. The end result of this activity is a 3D graph, and solutions to the system of linear equations can be generated through the use of technology. For the third meeting, Activity Sheet 3 (LAS 3) is provided. The test questions are displayed in Figure 9.

**PERMASALAHAN**

Jika Rani ingin memesan paket A dengan kemasan vakum, Nisa memesan Paket B dengan pengemasan terigu, dan Susi memesan Paket C dengan kemasan minyak. Namun jika mereka ingin membeli dengan harga satuan diluar paket maka mereka cukup membayar Rp. 1.500,00/pcs, diluar biaya pengemasan. Dapatkah kalian membantu mereka mempertimbangkan untuk membeli harga satuan atau paketan seperti di atas. Untuk dapat mengetahui perbandingan harganya, kalian perlu menghitung harga satuan pempek tersebut dengan menggunakan penyelesaian sistem persamaan linear tiga variabel.

1. Buatlah sistem persamaan linear tiga variabel yang terbentuk dari pesanan Rani, Nisa, dan Susi?

Jawab:

Figure 9. Test Questions

An example answer for LAS 3 is shown in Figure 10.

Jawab:

- PAKET A : Lenjer : 10, adaan : 20 = Rp. 165.000,00
- PAKET B : adaan : 20, Lenjer : 10, kulit : 10 = Rp. 200.000,00
- PAKET C : Lenjer : 20, adaan : 20, kulit : 10 = Rp. 250.000,00

$$\begin{cases} A = 10x + 20y = 165.000 \\ B = 10x + 20y + 10z = 200.000 \\ C = 20x + 20y + 10z = 250.000 \end{cases}$$

Jawab:

$$A = 10x + 20y = 165.000$$

$$B = 10x + 20y + 10z = 200.000$$

$$C = 20x + 20y + 10z = 250.000$$

Eliminasi:

$$\begin{array}{r} 10x + 20y + 10z = 200.000 \\ 20x + 20y + 10z = 250.000 \\ \hline -10x = -50.000 \\ \hline x = 5.000 \end{array}$$

$$\begin{array}{r} 10x + 20y = 165.000 \\ 10(5.000) + 20y = 165.000 \\ 50.000 + 20y = 165.000 \\ 20y = 165.000 - 50.000 \\ 20y = 115.000 \\ \hline y = 5.750 \end{array}$$

$$\begin{array}{r} 10x + 20y + 10z = 200.000 \\ 10(5.000) + 20(5.750) + 10z = 200.000 \\ 50.000 + 115.000 + 10z = 200.000 \\ 165.000 + 10z = 200.000 \\ 10z = 200.000 - 165.000 \\ 10z = 35.000 \\ \hline z = 3.500 \end{array}$$

Figure 10. Response from Research Subject 1

Based on the above answers, the learning trajectory set out in the initial conjecture was not fully achieved in this activity. Specifically, students showed a limited understanding of the given problems, resulting in difficulties when translating these problems into mathematical models. Consequently, the students were unable to fully complete the task and demonstrated only a few indicators.

From interviews with the research subjects, it was revealed that students neglected to write down important information about the given problems. This issue stemmed from their existing learning habits, where they would directly proceed to variable reasoning. Additionally, they encountered errors in their mathematical modeling, which subsequently affected their final solutions. Time constraints also played a role in their inability to fully complete the tasks.

### Discussion

The research results indicate that STEM-based learning, within the context of vacuum-sealed pempek packaging, has had a positive impact on students' understanding of three-variable linear equation systems. In this study, critical thinking indicators, as outlined by Facione (2015) namely interpretation, analysis, evaluation, and inference. Were successfully integrated into the learning process.

Students successfully understood and translated mathematical problems into three-variable linear equations. This indicator was present across all student groups on the first question, demonstrating the effectiveness of this teaching method in imparting fundamental concepts. There was an improvement in students' analytical abilities to connect given information and solve it in the form of linear equations. Although only three groups answered correctly, it suggests that STEM-based learning encourages analytical thinking. The evaluation indicator appeared in several groups, where students were able to review their own answers. This showcases a development in students' self-evaluation skills. The ability to draw logical

conclusions was evident in the majority of groups, indicating that students were able to infer from the activities carried out. However, it should be noted that some students provided incorrect or incomplete answers.

This research demonstrates a significant difference between the initial and final tests, confirming that the STEM-based learning approach is effective in enhancing both the understanding and critical thinking skills of students. This finding aligns with prior research emphasizing the importance of STEM education for the development of students' critical thinking capabilities (Khaeruddin & Bancong, 2022). For instance, STEM education has been shown to foster critical thinking skills in areas such as biology (Yaki, 2022) and physics (Pangesti & Triyanta, 2022). Against this backdrop, the current study provides nuanced insights into how STEM education can be specifically applied in the context of three-variable linear equation systems. Overall, the research contributes to the existing body of literature by offering compelling evidence for the efficacy of STEM-based learning approaches in the realm of mathematics, thereby laying the groundwork for further research on how this pedagogy can be optimized across various student ability levels.

The study strengthens the case that STEM-based learning methods are efficacious in teaching three-variable linear equation systems and in cultivating students' critical thinking skills. However, it also acknowledges that there is room for improvement in accommodating a diverse range of student abilities, particularly those at the lower end of the spectrum. This can serve as a springboard for additional research into designing STEM education that is both inclusive and effective, ensuring that all students can fully benefit from this approach.

### ***Implication***

The results of this research support the use of STEM-based approaches for instructing students in three-variable linear equation systems, validating its effectiveness in enhancing student comprehension and critical thinking capabilities. This endorsement encourages the integration of innovative methods into math teaching, serving as a guide for educators in crafting more interactive and integrated curricula. While the approach proves effective, the study also notes that additional support may be needed for students with lower abilities. This underscores the necessity of an inclusive educational model that provides all students, irrespective of their ability levels, with the requisite support for success. This aligns with the broader goals of equitable and inclusive education.

Incorporating the local and cultural context of vacuum-sealed pempek packaging as an example in the learning material highlights how mathematical content can be meaningfully integrated into everyday life scenarios. This can enhance the subject's relevance and resonance with students, thereby elevating their interest and motivation in learning mathematics. The focus on critical thinking skills in this research emphasizes the importance of nurturing these capabilities in math education, which aligns with the global demand for 21st-century skills and can form an integral part of mathematics education in Indonesia.

### ***Limitation and Suggestion for Further Research***

The current study has several limitations. Among them, the pre-existing lack of mastery over algebraic concepts among the participants stands out, as does the time constraint imposed on the test, which hindered the students from performing optimally. This research also opens the

door to further studies focusing on the design and implementation of more inclusive and effective STEM education, including ways to cater to students with varying levels of ability.

## CONCLUSIONS

The designed learning trajectory that teaches three-variable linear equation systems using the context of vacuum-sealed pempek packaging has proven to be effective, not just in improving comprehension of the material but also in fostering critical thinking abilities among students. Through the integration of STEM concepts, students are engaged in a deeper cognitive process, leading to improvements in interpretation, analysis, evaluation, and inference. These findings affirm that creative and contextual educational approaches can make a positive contribution to the enhancement of the quality of mathematics education and the development of students' critical thinking skills.

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## AUTHOR CONTRIBUTIONS STATEMENT

ANP acted as the lead researcher and was instrumental in generating the study's idea and designing the STEM-based mathematics learning framework. NA and S functioned as supervising professors, aiding the researcher in the completion of the study.

## REFERENCES

- Baskaran, V. L., & Abdullah, N. (2021). [Critical success factors of authentic learning teacher competency: Teachers' perception](#). *International Journal of Academic Research in Progressive Education and Development*, 10(3), 61-81.
- Basri, H., Purwanto, P., As'ari, A. R., & Sisworo, S. (2019). [Investigating critical thinking skill of junior high school in solving mathematical problem](#). *International Journal of Instruction*, 12(3), 745-758.
- Cailloux, O., & Meinard, Y. (2019). [A formal framework for deliberated judgment](#). *Theory and Decision*, 88(2), 1-36.
- Council, N. R. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
- Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). [Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study](#). *International Journal of STEM Education*, 5(1).
- Facione, P. (2015). Critical thinking: What it is and why it counts. *Insight Assessment*.
- Falcó-Pegueroles, A., Rodríguez-Martín, D., Pozón, S. R., & Zuriguel-Pérez, E. (2020). [Critical thinking in nursing clinical practice, education and research: From attitudes to virtue](#). *Nursing Philosophy*, 22(1).

- Handayani, S., Mintarti, S., Megasari, R., & Omar, N. (2020). [Developing of STEM-based learning models for economic education student for facing Industry revolution 4.0 in East Java](#). *E3S Web of Conferences*, 153.
- Ilyas, M., Meiyani, E., Ma'rufi, M., & Kaewhanam, P. (2022). [Improving students' ability in learning mathematics by using the science, technology, engineering, and mathematics \(STEM\) approach](#). *Frontiers in Education*, 7.
- Karahan, E., Bilici, S. C., & Unal, A. (2015). [Integration of media design processes in science, technology, engineering, and mathematics \(STEM\) education](#). *Eurasian Journal of Educational Research*, 15(60), 221-240.
- Khaeruddin, K., & Bancong, H. (2022). [STEM education through PhET simulations: An effort to enhance students' critical thinking skills](#). *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, 11(1), 35-45.
- Kong, S. F., & Matore, M. E. E. M. (2021). [Can a science, technology, engineering, and mathematics \(STEM\) approach enhance students' mathematics performance?](#). *Sustainability*, 14(1), 1-15.
- Lee, K. (2020). [Autoethnography as an authentic learning activity in online doctoral education: An integrated approach to authentic learning](#). *TechTrends*, 64(4).
- Lestari, A. A. P., Nugroho, A. A., & Nursyahidah, F. (2021). [Desain pembelajaran refleksi dan translasi berkonteks Klenteng Sam Poo Kong Semarang](#). *Jurnal Elemen*, 7(2), 381-393.
- Maruf, A. S., Wahyu, W., & Sopandi, W. (2020). [Colloidal learning design using radec model with stem approach based google classroom to develop student creativity](#). *Journal of Educational Sciences*, 4(4), 758-765.
- Pangesti, K. I., & Triyanta, N. (2022). [STEM project topics relevant to the physics curriculum at high school level](#). *Journal of Physics: Conference Series*, 2243(1).
- Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2021). [Teaching mathematics with mobile devices and the Realistic Mathematical Education \(RME\) approach in kindergarten](#). *Advances in Mobile Learning Educational Research*, 1(1), 5-18.
- Priemer, B., Eilerts, K., Filler, A., Pinkwart, N., Rösken-Winter, B., Tiemann, R., & Belzen, A. U. zu. (2019). [A framework to foster problem-solving in STEM and computing education](#). *Research in Science & Technological Education*, 38(1), 1-26.
- Sachdeva, S., & Eggen, P.-O. (2021). [learners' critical thinking about learning mathematics](#). *international Electronic Journal of Mathematics Education*, 16(3), 1-18.
- Suryani, Y. (2023). [The effectiveness of investigation group learning model based on marzano's instructional framework in improving students' higher order thinking skill](#). *KnE Social Sciences*, 843-861.
- Tomesko, J., Cohen, D., & Bridenbaugh, J. (2022). [Using a virtual flipped classroom model to promote critical thinking in online graduate courses in the United States: A case presentation](#). *Journal of Educational Evaluation for Health Professions*, 19.
- Wahono, B., Lin, P., & Chang, C.-Y. (2020). [Evidence of STEM enactment effectiveness in Asian student learning outcomes](#). *International Journal of STEM Education*, 7(1), 1-18.
- Widana, I. W., Sopandi, A. T., & Suwardika, G. (2021). [Development of an authentic assessment model in mathematics learning: A science, technology, engineering, and mathematics \(STEM\) approach](#). *Indonesian Research Journal in Education |IRJE|*, 5(1), 192-108.
- Yaki, A. A. (2022). [Fostering critical thinking skills using integrated STEM approach among secondary school biology students](#). *European Journal of STEM Education*, 7(1). 1-10.

Yıldırım, B. F., & Sidekli, S. (2018). [STEM applications in mathematics education: The effect of stem applications on different dependent variables](#). *Journal of Baltic Science Education*, *17*(2), 200-214.