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Development of Science, Technology, Engineering and Mathematics (STEM)-Based Science Learning Devices to Improve Critical Thinking and Problem Solving Skills in Elementary School Students

Arika Hary Cahyono[1*], Muslimin Ibrahim[2], Nadi Suprapto[3]

[1,2,3]Pascasarjana, Surabaya State University
Lidah Wetan, Kec. Lakarsantri, Kota Surabaya, Jawa Timur, Indonesia 60213

*Correspondinge-mail: arika.18048@mhs.unesa.ac.id

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Abstract: This research focuses on developing science, technology, engineering, and mathematics (STEM)-based learning tools for fourth-grade elementary school students in science subjects. The purpose of this research is to improve students' critical thinking skills and problem-solving through the use of STEM-based learning tools. The research and development design in this study used an adaptation of the Dick and Carey development model, field trials with a one-group pretest-posttest design. Data collection techniques through observation, questionnaires, and tests. Data analysis techniques to determine the validity, practicality, and effectiveness of learning devices are descriptive qualitative with Aiken's V content validity coefficient techniques and percentage techniques. The results of the quality of learning device products in the validity aspect mostly achieve a value of V = 0.83 - 1 on each item measured so that it can be concluded that the product is very valid and feasible to use. The quality of developing products based on practical aspects includes the implementation of learning steps by teachers and students which reach 89.5% and 87.3% with very well-implemented categories, the quality of product development based on aspects of effectiveness is based on an increase in students' critical thinking skills and problem-solving. The results of the data analysis showed that there was a significant increase in students' posttest results after participating in STEM-based science learning compared to pretest results before learning. Includes an increase in classical mastery of learning outcomes from 25% to 82.14%. This means there are significant differences in students' critical thinking skills and problem-solving after participating in learning by applying STEM-based science learning tools.

Keywords:. science, technology, engineering, and mathematics (STEM), critical thinking, problem solving

Abstrak: Penelitian ini berfokus pada pengembangan perangkat pembelajaran berbasis STEM bagi siswa kelas empat SD mata pelajaran IPA. Tujuan penelitian ini adalah untuk meningkatkan kemampuan berpikir kritis dan pemecahan masalah siswa melalui penggunaan perangkat pembelajaran berbasis STEM. Desain penelitian dan pengembangan dalam penelitian ini menggunakan adaptasi model pengembangan Dick and Carey, uji coba lapangan dengan desain one-group pretest-posttest. Teknik pengumpulan data melalui observasi, angket, dan tes. Teknik analisis data untuk mengetahui validitas, kepraktisan, dan efektivitas perangkat pembelajaran bersifat deskriptif kualitatif dengan teknik koefisien validitas isi V Aiken dan teknik persentase. Hasil kualitas produk perangkat pembelajaran pada aspek validitas sebagian besar mencapai nilai V = 0,83 – 1 pada setiap item yang diukur sehingga dapat disimpulkan bahwa produk tersebut

sangat valid dan layak digunakan. Kualitas pengembangan produk berdasarkan aspek praktis meliputi pelaksanaan langkah-langkah pembelajaran oleh guru dan siswa yang mencapai 89,5% dan 87,3% dengan kategori yang sangat terimplementasi dengan baik, kualitas pengembangan produk berdasarkan aspek efektivitas didasarkan pada peningkatan kemampuan berpikir kritis siswa dan pemecahan masalah. Hasil analisis data menunjukkan bahwa terdapat peningkatan yang signifikan pada hasil posttest siswa setelah mengikuti pembelajaran IPA berbasis (STEM) dibandingkan dengan hasil pretest sebelum pembelajaran. Termasuk peningkatan penguasaan hasil belajar klasikal dari 25% menjadi 82,14%. Ini berarti ada perbedaan yang signifikan dalam keterampilan berpikir kritis dan pemecahan masalah siswa setelah berpartisipasi dalam pembelajaran dengan menerapkan perangkat pembelajaran (STEM).

Kata kunci: science, technology, engineering, and mathematics (STEM), berpikir kritis, pemecahan masalah.

▪ INTRODUCTION

The quality of human resources is the key to the progress of a nation. In the 4.0 revolution era, major changes occurred in various sectors, high competition, and many complex problems in this era became a challenge for the nation's next generation.

Education plays an important role in preparing a generation that is ready to compete globally. The competencies of students needed at this time are not only students who are good at calculating, quick to memorize, or able to work on questions in a short time, but also students who master 21st-century thinking and learning skills and are empowered in teaching and learning activities. 21st-century thinking and learning skills can become social capital and intellectual capital including communication, collaboration, critical thinking and problem-solving, and creativity and innovation (Trilling and Fadel, 2009:49).

Education is an effort made to prepare students through learning activities that aim to help students actively develop their potential, abilities, and talents. Permendikbud number 65 of 2013 concerning process standards for primary and secondary education which contains the importance of the learning process using the principles of a scientific approach.

Education influences the quality of human resources which can be seen from the ability of its graduates to master skills, and technology, and have extensive knowledge and professional expertise. On that basis, Education must be an opportunity to empower students through thinking skills and problem-solving. These two skills must be taught and trained to students from an early age starting at the elementary school level.

The field shows that critical thinking skills and problem-solving are still low. This fact is supported by the results of PISA (Program for International Students Assessment) research in 2015 which was published in 2016 and showed that Indonesia has an average score of 403 out of the international averages of 500 and 501. TIMSS research data (Trends in International Mathematics and Science Study) in 2015, Indonesia ranks 69th out of 76 countries involved.

On a local scale in Surabaya which was successfully observed in the 2022/2023 academic year at Bubutan IV Surabaya Elementary School, the researcher obtained an overview of the conditions of the students during the teaching and learning process, namely showing low and passive student activity in the teaching and learning process. Teachers have not implemented innovative learning models. The learning process in the classroom is still centered on the teacher who uses the lecture method with the help of a blackboard to convey the subject matter to students. The learning process which is teacher-centered and uses the lecture method causes students to be less active and students' enthusiasm for participating in learning tends to be low. Some students are busy themselves even doing activities that do not support learning. During the learning process, students tend to be passive, this can be seen from the fact that most students are silent when allowed to ask or answer questions. Whereas when students are appointed to answer questions only some students can answer questions perfectly.

In 2030 Indonesia is expected to be in the 7th position as the country with the strongest economy in the world. Four potential sectors will sustain Indonesia's economy in the future, namely consumer services or services, agriculture and fisheries, natural

resources, and education. Indonesia needs 113 million workers with adequate skills and expertise to make this happen. This is based on data from the Central Bureau of Statistics in 2016 put forward by the McKinsey Global Institute. This is the low ability of critical thinking and problem solving as well as future predictions of workforce need indicating the increasing need for critical thinking skills and problem-solving to be taught to students. Because by practicing thinking skills and problem-solving can overcome the problem of low-quality educational outcomes while providing a skilled workforce.

To make this happen, a method is proposed by conducting learning that implements STEM. STEM is an approach formed based on a combination of several disciplines, namely Science, Technology, Engineering, and Mathematics. Collaboration in the learning process, STEM will help students to collect and analyze and solve problems that occur and be able to understand the relationship between a problem and other problems (Handayani, 2014: 62).

STEM-based education forms human resources (HR) who can reason and think critically, logically, and systematically so that they will be able to face the challenges of the 21st century and be able to improve the country's economy. The ability to master science can train in the process of understanding the world and the ability to participate in making decisions that affect it. Mastery of technology is useful for analyzing how new technology affects individuals, communities, nations, and the world. Mastery of engineering can help understand how technology can be developed through engineering/design processes by integrating different lessons and finally mathematics is expected to be able to analyze reasons, communicate ideas effectively and be able to find solutions to various problems in different situations.

The effectiveness of a lesson is very dependent on the lesson plan designed by the teacher. Concerning science learning tools, through observation activities, it is known that the lesson plans used by teachers are still dominated by lectures, question and answer and there are no variations in learning models that lead to improving students' critical thinking skills Student Activity Sheet (LKPD) used by the teacher has not been developed by himself but instead uses practice questions in student books. In addition, learning is oriented to thematic textbooks only, no development is tailored to the characteristics of students.

Based on the explanation above, it can be concluded that the learning tools prepared by teachers are generally still unable to accommodate efforts to improve the critical thinking skills that students should have. There fore the development of appropriate learning tools by applying an effective and student-centered learning approach is necessary.

The STEM approach is expected to have an impact on students to solve problems, design/create new things (innovation), understand themselves, think logically and master technology. The STEM approach is focused on the real world and authentic problems so that students can learn to reflect on the problem-solving process. Through the STEM approach, students can have deep insight and are dynamic and creative to create a superior generation. 21st-century skills or what is termed 4C (Communication, Collaboration, Critical Thinking and Problem-solving, and Creativity and Innovation) are real abilities to aim for with the 2013 Curriculum. Critical thinking and Problem solving (critical thinking and problem solving) is the ability to understand a complicated problem,

connecting information, so that in the end various perspectives appear, and find solutions to a problem. Critical thinking is also interpreted as the ability to reason, understand and make complex choices, understand the interconnections between systems, compile, express, analyze, and solve problems.

▪ METHOD

This research is research and development to produce products and test their effectiveness until they are declared fit for use. The product to be developed is a science learning tool based on the STEM learning model in improving critical thinking skills and problem-solving in elementary schools. The learning tools developed in this study are Learning Implementation Plans (RPP), Student Teaching Materials (BAS), Student Activity Sheets (LKPD), and Student Assessment Sheets.

This study uses a modification of the Dick and Carey research development design model which consists of 10 development steps, namely: (1) Identify instructional goals/identify learning objectives, (2) Conduct instructional analyses/conduct learning analysis, (3) Analyze learner and content/analysis student character and material, (4) write performance objectives/ formulate specific learning objectives, (5) Develop assessment instruments/ develop research instruments, (6) Develop instructional strategies/ develop learning strategies, (7) Develop and select instructional materials/ develop and selecting teaching materials, (8) Design and conduct a formative evaluation of instruction/ develop and carry out a formative evaluation, (9) Revise instructional/ revise instructional activities, (10) Design and conduct summative evaluation/ design and implement the summative evaluation.

This research product will be tested on fourth-grade students at SDN Bubutan IV in the odd semester of the 2022/2023 academic year. Product trials aim to obtain an assessment of the quality of the devices being developed so that they can be declared feasible and effective for use. The trials that will be implemented include expert trials, individual trials, small group trials, and field trials using the one-group pretest-posttest research design as follows:

Kelas	***Pretest***	**Perlakuan**	***Postest***
Trial class	T_1	X	T_2

Data collection techniques and instruments used in this study are

Validation

Learning device validation is used to find out whether the learning tools that have been developed are feasible to apply. Validation was carried out by 2 validators, namely expert lecturers and the instrument used was a learning device validation sheet. The results of the validation assessment were processed using the Aiken formula.

$$V = \sum S/[n(c-1)]$$

In addition to assessing the feasibility of the validator, the legibility of the BAS and LKPD is also measured, which can be expressed by the following formula:

$$Legibility = \frac{\sum Correctly\ filled\ word}{\sum The\ whole\ word} \text{ x } 100\%$$

Assessment

Assessment is used to determine the extent to which students achieve in aspects of critical thinking skills and problem-solving. The assessment instrument used is the evaluation sheet. Assessment is carried out before the lesson (Pre-test) and after attending the lesson (Post-test). The data obtained will be analyzed using the percentage calculation as follows:

$$\text{Assessment of critical thinking skills and problem solving} = \frac{\text{Score obtained}}{\text{Maximum score}} \text{ x } 100$$

The completeness criterion is if students achieve a minimum score of 75. As well as class completeness is achieved if 75% of students succeed in achieving individual completeness.

Observation

Observation activities are carried out during learning by using observation sheets. Observations were made to assess the implementation and suitability of learning with the learning implementation plan as well as the level of student activity which will then be analyzed in a quantitative description using the following formula:

$$P = \frac{Tse}{N} \text{ x } 100\%$$

RPP is declared implemented if 100% of the assessment aspects of the applicability of the device and student activity are successful in learning with a minimum score of 3 according to the observations of the observer.

Questionnaire

Questionnaires are used to determine students' responses to learning, responses regarding teaching materials, and worksheets used during learning. The Guttman scale questionnaire that is made contains statements that need to be answered with the answer choices "Yes" which has a value (1) and "No" which have a value (0). To analyze data from a questionnaire using the following formula:

$$Percentage\ of\ student\ responses = \frac{A}{N} \text{ x } 100\%$$

▪ RESULT AND DISCUSSION

The following is the result of the validation of learning tools including validation of lesson plans, LKPD, BAS, and evaluation questions using Aiken's V content validity coefficient technique

No. Item	Validator 1		Validator 2		Σs	V	Ket.
	Skor	S	Skor	S			
1	4	3	4	3	6	**1**	**ST**
2	4	3	4	3	6	**1**	**ST**
3	4	3	4	3	6	**1**	**ST**
4	4	3	4	3	6	**1**	**ST**
5	4	3	3	2	5	**0,83333**	**ST**
6	3	2	4	3	5	**0,83333**	**ST**
7	3	2	3	2	4	**0,66667**	**ST**
8	4	3	3	2	5	**0,83333**	**ST**
9	4	3	4	3	6	**1**	**ST**
10	4	3	4	3	6	**1**	**ST**
11	3	2	4	3	5	**0,83333**	**ST**
12	4	3	4	3	6	**1**	**ST**
13	4	3	4	3	6	**1**	**ST**
14	3	2	4	3	5	**0,83333**	**ST**
15	4	3	4	3	6	**1**	**ST**

Table 1. Validation Results RPP

Based on the table above, it can be seen that the validation results by 2 expert lecturers show that the lesson plans that have been made are very feasible to apply in learning. Of the 15 items measured, there were 14 items with a score of V = 0.8 - 1 or having very high validity and there was 1 item with a score of V = 0.6 or having high validity.

No. Item	Validator 1		Validator 2		Σs	V	Ket.
	Skor	S	Skor	S			
1	4	3	4	3	6	**1**	**ST**
2	3	2	4	3	5	**0,83333**	**ST**
3	4	3	3	2	5	**0,83333**	**ST**
4	4	3	4	3	6	**1**	**ST**
5	4	3	4	3	6	**1**	**ST**
6	4	3	4	3	6	**1**	**ST**
7	4	3	4	3	6	**1**	**ST**
8	4	3	4	3	6	**1**	**ST**
9	3	2	4	3	5	**0,83333**	**ST**
10	4	3	4	3	6	**1**	**ST**
11	4	3	3	2	5	**0,83333**	**ST**

Table 2. LKPD Validation Results

Based on the table above, it can be seen that the validation results by 2 expert lecturers show that the LKPD that has been made is very feasible to be applied in learning. Of the 11 items measured, all items achieved a score of V = 0.8 - 1 or had very high validity.

No. Item	Validator 1		Validator 2		Σs	V	Ket.
	Skor	S	Skor	S			
1	4	3	4	3	6	**1**	**ST**
2	4	3	4	3	6	**1**	**ST**
3	3	2	4	3	5	**0,83333**	**ST**
4	4	3	4	3	6	**1**	**ST**
5	3	2	4	3	5	**0,83333**	**ST**
6	3	2	4	3	5	**0,83333**	**ST**
7	4	3	4	3	6	**1**	**ST**
8	4	3	4	3	6	**1**	**ST**
9	4	3	3	2	5	**0,83333**	**ST**

Table 3. BAS Validation Results

Based on the table above, it can be seen that the validation results by 2 expert lecturers show that the Student Teaching Discussion (BAS) that has been made is very feasible to be applied in learning. Of the 9 items measured, all items achieved a score of V = 0.8 - 1 or had very high validity.

No. Soal	Item 1				Item 2				Item 3				Item 4				Item 5				Item 6			
	V1		V2		V1		V2		V1		V2		V1		V2		V1		V2		V1		V2	
	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S	Skor	S
1	4	3	4	3	3	2	4	3	4	3	4	3	3	2	4	3	4	3	4	3	4	3	4	3
2	3	2	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3
3	4	3	4	3	4	3	4	3	3	2	3	2	4	3	4	3	3	2	3	2	3	2	4	3
4	3	2	3	2	3	2	3	2	4	3	3	2	4	3	3	2	4	3	3	2	4	3	3	2
5	4	3	4	3	4	3	3	2	3	2	4	3	3	2	4	3	4	3	4	3	3	2	3	2
6	4	3	4	3	4	3	4	3	4	3	4	3	3	2	4	3	3	2	4	3	4	3	4	3
7	4	3	3	2	3	2	3	2	4	3	3	2	4	3	3	2	4	3	3	2	4	3	3	2
8	4	3	4	3	4	3	4	3	3	2	3	2	4	3	4	3	3	2	3	2	3	2	4	3
9	3	2	3	2	3	2	3	2	4	3	3	2	4	3	3	2	4	3	3	2	4	3	3	2
10	4	3	3	2	3	2	3	2	4	3	3	2	4	3	3	2	4	3	3	2	4	3	3	2
Σx	53				50				51				53				51				52			
V	0,88				0,83				0,85				0,88				0,85				0,87			
Ket.	ST				ST				ST				ST				ST				ST			

Table 4. Evaluation Sheet Validation Results

Based on the table above, it can be seen that the validation results by 2 expert lecturers show that the Evaluation Sheet that has been made is very feasible to apply in learning. Of the 6 items measured, all items achieved a score of V = 0.8 - 1 or had very high validity.

The results of the LKPD and BAS legibility questionnaire assessment given to 3 students in the individual trial and 9 students in the small-scale trial can be presented in diagram 1 below:

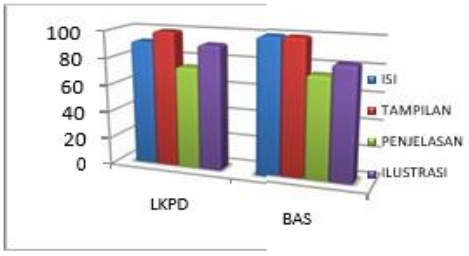

Diagram 1. Assessment of Readability of LKPD and BAS

The implementation of learning devices was measured using observation sheets for teacher and student activities by 2 colleagues during the implementation of learning and obtained the following results:

No	Aspek yang diamati	P1		P2		Ket
		O1	O2	O1	O2	
1	Jumlah	84	86	93	94	
2	Rata-rata	3,23	3,31	3,58	3,62	
3	Persentase (%)	81%	83%	89%	90%	
4	Predikat	SB	SB	SB	SB	

Table 5. Average Student Activity Observation Results

Based on the table above, it can be seen that the results of observations from colleagues regarding student activities at the first meeting reached 81% by observer 1 and 83% by observer 2. Meanwhile, at the second meeting learning reached 89% by observer 1 and 90% by observer 2. So it can be concluded that in learning meeting 1 and meeting 2, student activities meet very good criteria.

No	Aspek yang diamati	P1		P2		Ket
		O1	O2	O1	O2	
1	Jumlah	78	77	82	85	
2	Rata-rata	3,23	3,31	3,58	3,62	
3	Persentase (%)	89%	88%	93%	97%	
4	Predikat	SB	SB	SB	SB	

Table 6. Average Observation Results of Learning Implementation

Based on the table above, it can be seen that the results of observations from colleagues regarding the implementation of learning at the first meeting reached 89% by observer 1 and 88% by observer 2. Meanwhile, at the second meeting learning reached 93% by observer 1 and 97% by observer 2. So it can be concluded that at learning meeting 1 and meeting 2, the implementation of learning meets the very good criteria and is in accordance with the devices that have been made.

The results of the student response questionnaire assessment of science learning with STEM which was given after learning to 28 students can be presented in table 6 below:

No. Pernyataan	Kriteria		Skor	Prosentase
	Ya	Tidak		
Pertanyaan 1	24	4	24	86%
Pertanyaan 2	22	6	22	79%
Pertanyaan 3	25	3	25	89%
Pertanyaan 4	25	3	25	89%
Pertanyaan 5	23	5	23	82%
Pertanyaan 6	26	2	26	93%
Pertanyaan 7	21	7	21	75%
Pertanyaan 8	22	6	22	79%
Pertanyaan 9	23	5	23	82%
Pertanyaan 10	23	5	23	82%
			234	**836%**
				83,57%

Table 7. Student Response Questionnaire Results

Based on the table above, shows that most students respond well to learning science with STEM, namely reaching a percentage of 83.57%.

Pretest and posttest data of students before and after participating in STEM-based science learning are presented in the following table:

No.	Keterangan	Nilai	
		Pretest	*Posttest*
1	Nilai Terendah	40	60
2	Nilai Tertinggi	86	100
3	Ketuntasan Klasikal	25%	82%
4	Total Nilai	1739	2365
5	Rata-rata	62,1	84,5

Table 8. Pretest and Posttest Results

From the table above it can be seen that there was a significant increase in the results of the students' pretest and posttest before and after STEM-based science learning. The average grade of the students increased from 62.1 to 84.5 and the class's classical completeness also increased from 25% to 82%. So it can be concluded that science, technology, engineering, and mathematics (STEM)-based science learning can improve students' critical thinking skills and problem-solving

▪ CONCLUSION

Based on the results of validation, testing, observation, and data analysis in this study, it can be concluded that: The science, technology, engineering, and mathematics (STEM)-based science learning tools that have been developed meet the criteria for proper implementation according to the validation results of the two expert validators. The science, technology, engineering, and mathematics (STEM)-based science learning tools that have been developed meet practicality criteria as indicated by high applicability,

increased student activity, positive student responses, and easy-to-understand LKPD and BAS legibility. The science, technology, engineering, and mathematics (STEM)-based science learning tools that have been developed meet the criteria for effectiveness as indicated by an increase in students' critical thinking skills and problem-solving.

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