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Research Article

The effectiveness of STEM based inquiry learning packages to improving students' critical thinking skill

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Abstract

STEM is integrated learning which consists of four aspects namely science, technology, engineering, and mathematics. The 5M inquiry is a learning model that is being promoted in Indonesia to increase the critical thinking skills of students. In this study the 5M inquiry learning activity was integrated with the STEM aspects in developing students' critical thinking skills in learning packages of simple machine materials. This study aimed to determine the effectiveness of STEM-based inquiry learning packages in simple machine material for improving the critical thinking skills of junior high school students. This type of research used quasi-experimental research with a one-shot case study pretest-posttest design. The research was replicated in four of 2nd grade of Junior High School 1 Pamekasan which conducted to 112 of students. The sampling technique used purposive sampling based on the fact that students were quite familiar with excavators. Data collection was used by tests of students' critical thinking skills and questionnaires of students' responses. The critical thinking skills test was given to students before and after the learning process, students were given the same initial test (pre-test) and final test (post-test). Questionnaires of students' responses were given to students after the learning process with STEM-based inquiry learning. Data analysis used descriptive analysis, normalized gain (N-gain) score, and paired t-test. The results showed that: 1) the increase of critical thinking skills based on the N-gain score is the high category; 2) the result of paired t-test showed that there is a significant difference in students' critical thinking skills before and after learning with STEM-based inquiry learning; 3) the student's response is the positive response with very good criteria to STEM-based inquiry learning. Based on the study, STEM-based inquiry learning packages were effective in improving the critical thinking skills of junior high school students.

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Introduction

STEM (Science, Technology, Engineering, and Mathematics) have an important role in learning for improving the abilities of the 21st century (Bybe, 2010; Hernandez, et al., 2014). Facing the globalization of the world, 21st-century abilities such as collaboration, digital literacy, critical thinking, and problem-solving are very important for individuals (Partnership, 2016). Learning was directed to practicing analytical thinking skills and collaboration to solving the surrounds of problems (Marsono et al., 2017). Thibaut, Sitjin and Haydee (2018) stated that professionalism is needed for dealing with problems in the 21st century. Ostler (2012) stated that this ability involves STEM aspects for overcoming these problems. Human work requires mastery of STEM (Rothwell, 2013). STEM learning involves

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interdisciplinary, authentic, and contextual knowledge, that is science, technology, engineering, and mathematics (LaForce et al., 2016; Holmlund et al., 2018). STEM emphasizes activities that involve problem-solving with inquiry activities (Baharin et al., 2018). STEM learning is related to inquiry activities through the formulation of questions that are designed and then solved through investigation (Kennedy & Odell, 2014).

Inquiry learning is a signal of paradigm friction from teacher-centered learning to student-centered learning (Ramnarain & Mupira, 2018). Students were directly involved in problems solving, making decisions, and not just thinking passively. Students were prepared to make decisions about social life around. Inquiry learning encourages students to learn through complicity in real contexts (Ghaemi & Mirsaeed, 2017). Students are accustomed to thinking about the problems around them. Inquiry learning can improve the academic performance and critical thinking skills of students (Byker et al., 2017).

According to Ennis (1993), critical thinking is reasonable and reflective thinking which focuses on deciding what to believe or do. Critical thinking allows students to evaluate evidence, assumptions, logic, and the language that underlies the statements of others (Larmer & Mergendoller, 2010). Critical thinking as a constructivist analysis process is used in defining a problem, determining actions to be taken, deciding, and evaluating what is happening. (Duran & Şendağ, 2012). Critical thinking has become a necessity in the competition to face all kinds of problems in life today.

Students' critical thinking skills in the 21st century can be developed through proper management of the learning process (Tunkham, Donpudsa & Dornbundit, 2016). Learning is carried out by actively involving students to construct their knowledge. Beers (2011) stated that STEM (Science, Technology Engineering, Mathematics) as an innovative effort consists of 4Cs, namely creativity, critical thinking, collaboration, and communication for overcoming the problems. In STEM learning, students are allowed to solve problems around them through the concepts and knowledge they have (Baharin et al., 2018) by trying new things to face new things (Linder et al., 2016). Tomkin et al., (2019) stated that STEM forming students' cognitive abilities to think critically well.

STEM is a scientific methodology that teaches each STEM concept in an integrated and inseparable manner covering aspects of science, technology, engineering, and mathematics (Brown et al., 2011). STEM teachers are expected to be able to connect learning with real-world contexts (Morrison, 2006) by developing STEM-based learning activities (Tunkham et al., 2016) which can be done through learning packages. Learning activities that involve students directly with integrated concepts in the STEM aspect (Stachwell & Loepp, 2002) as authentic learning which aims at STEM literacy (Ciolan & Ciolan, 2014).

STEM provides opportunities for students to use their learning experiences to encourage critical thinking skills, problem-solving, and rhythm (Stohlmann, Moore and Roehrig, 2012). STEM is an integrated approach that involves students actively (Shernoff, 2013) in accordance with the constructivism paradigm (Martin & Hansen, 2018). STEM shows motivation in learning activities, designing solutions, and utilizing technology (Tillman, An, Cohen, Kjellstrom & Boren, 2014). STEM can stabilize student interest and motivation (Chittum et al, 2017). Learning experiences that are student-centered, meaningful, interesting, and involve higher-order thinking and problem solving, related to STEM learning (Stohlmann, Moore & Roehrig, 2012) make students innovative, independent, proficient in technology, creative and making a decision based on thinking (Kenndedy & Odell, 2014).

Learning requires students to support and formulate questions or problems and answer questions through scientific activities (Šorgo, Dojer, Golob, Repnik, Repolusk, Pesek, Virtič, Šperniak, & Špur, 2018). The involvement of students will gain the ability to hypothesize, design activities, evaluate and reflect (Baharin, Kamarudin & Munaf, 2018) for solving real life problems with inquiry activities (Chinn & Malhotra, 2002). Taber (2013) stated that students can reconstruct their understanding based on previously acquired knowledge to learning becomes meaningful. Drake (2012) stated that STEM-based inquiry is a meaningful learning which makes students active and innovative.

In STEM learning, the four aspects of science, technology, engineering, and mathematics must be studied as one unit, but the facts that occur in Indonesia generally only study aspects of science and mathematics. Erman (2017) stated that in general students experience misconceptions, students have difficulty understanding science concepts. Students who are still difficult to understand science concepts will find it very difficult to learn through STEM. Inquiry learning using the 5M scientific approach applied in Indonesia generally experiences difficulties due to the limited scientific abilities of both students and teachers (Erman et al., 2018; Šorgo et al., 2018). Students also generally have difficulty learning science through socio-scientific issues (Erman et al, 2020; Šorgo et al., 2018). Currently, Indonesia is implementing 5M inquiry learning at elementary to high school to support the improvement of scientific literacy and students' critical thinking skills (Erman et al, 2020).

In this study, we assessing the effectiveness of STEM-based 5M inquiry learning packages which we have developed on a simple machine material. Simple machine material was chosen because it involved aspects of science, technology, engineering, and mathematics which were quite familiar and easy to find for students in their surroundings. Through STEM-based inquiry, students explain excavator technology products in the aspects of science, technology, engineering, and mathematics after learning and explaining the concept of a simple machine which is integrated into 5M inquiry who is familiar with Indonesian science teachers in general.

Problem of Study

Based on research shows that the STEM-based inquiry learning packages were valid to improving students' critical thinking skills, then an analysis of the effectiveness of STEM-based inquiry learning packages was carried out to improving students' critical thinking skills. In practice, this study conducted several analyzes including:

- How are students' critical thinking skills using STEM-based inquiry learning packages?
- How are students' responses to STEM-based inquiry learning packages?

Method

Research Model

This type of design research is a pretest-posttest design with a repeat design (Fraenkel et al., 2012). Repetitions were carried out on 4 groups of 2nd-grade students of Junior High School.

Table 1.
Research Design Model

Group	Design
1	
2	O_1 X O_2
3	
4	

O_1 = pretest; X = treatment; O_2 = posttest

Participants

The population in this study were students of 2nd grade or VIII classes of Junior High School 1 Pamekasan. The research was conducted in 4 classes of class VIII students amount of 112 students. Repetition in 4 classes is carried out in a form to determine the consistency of effects in the learning carried out. The sampling technique was carried out by using the purposive sampling technique. The choice of this technique is based on the fact that students are quite familiar with excavators so it is assumed that it is easier to follow STEM-based inquiry learning on simple machine material to improve their critical thinking skills.

Data Collection Tools

The instruments in this study were a test of critical thinking skills and a student's response questionnaire. This instrument has been validated by 3 experts in the field of education/science using the scoring mode score given by the validator. The validation sheet contains components of assessment of the content, format, use of sentences, and conformity with learning indicators. The validation results show a value of 4 with very valid criteria to be used, while the mean of value the Conbrach Alfa reliability shows 0.848 degrees which it can be relied on in collecting data (Basuki & Hariyanto, 2014).

Students' Critical Thinking Skills

The instrument of critical thinking skills was multiple choices from which were accompanied by reasons and was given before and after learning using the packages developed. This form of assessment was not just right or wrong as a form of interpretive activities that students have done in learning (Rosebery et al., 2015). The test consists of 12 items covering critical thinking indicators (Ennis, 2011) with 3 questions of basic clarification indicator, 2 questions of decision indicator, 2 questions of inference indicator, 3 questions of advanced clarification indicator, and 2 questions of supposition and integration indicator.

Students' Responses

The student response questionnaire was a questionnaire given at the end of the learning process to find out the student's response to the learning is given to STEM based inquiry learning. The components of the assessment of student responses include aspects of learning renewability, interest, motivation, easily and expectancy in classroom learning. The criterion for the percentage of student responses uses a Likert scale. The rubric score used is from numbers 1-4, with a score of 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree.

Data Analysis

The research data were analyzed descriptively quantitatively. After obtaining the pretest and posttest scores on the students' critical thinking skill test, then a different test was carried out by a paired t-test statistical analysis with the criteria if the value was sig. > α (= 0.05): there is no difference in test results before and after using STEM-based inquiry learning (H0) and if the value is sig. <α (= 0.05): there are differences in test results before and after participating in STEM-based inquiry learning (H1). Furthermore, the increase in students' critical thinking skills was calculated using the N-gain formula. According to Hake (1999) N-gain (Ng) can be calculated with the following formula:

$$Ng = \frac{Sf - Si}{Smax - Si}$$

Sf is the posttest score; Si is the pretest score, and Smax is the maximum score of the test results. Furthermore, the results of the normalized gain calculation are interpreted according to the following criteria: 1) Low criteria if the score$Ng<0.3$; 2) Medium criteria if $0.3 \geq Ng < 0.7$; 3) High criteria if $0.7 \geq Ng \leq 1.0$.

The students' responses data given by students were analyzed using qualitative descriptive. Student's responses data are used to answer questions about how students respond whose using STEM-based inquiry learning packages to students' critical thinking skills. The percentage of student responses (P) uses a Likert scale, with the following calculations (Gronlund, 1981):

$$P = \frac{A}{B} x\ 100\%$$

A = number of answers; B = maximum number of answers. The interpretation of the student response criteria is as follows: 1) The fewer criteria if the score is ≤ 25; 2) Medium criteria if $25> P \leq 50$; 3) Good criteria if the score is $50> P \leq 75$; 4) The very good criteria if $75 > P \leq 100$.

Learning packages of STEM-based inquiry

Research Procedures

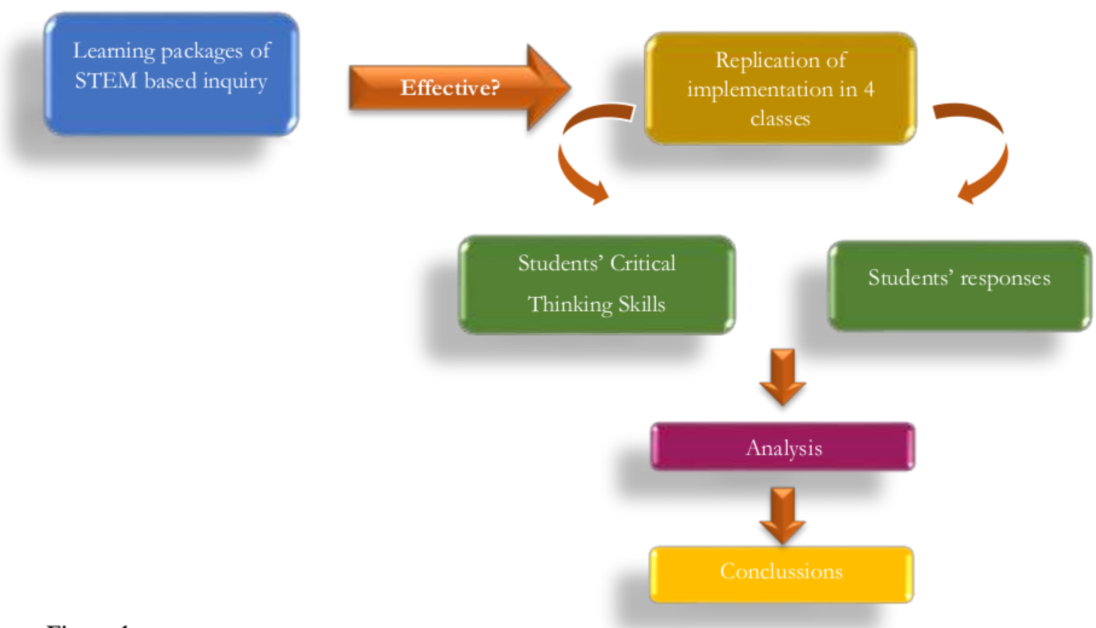


Figure 1.

Research Procedures

Results and Discussion

The effectiveness of this learning can be determined based on the research data on the test scores of critical thinking skills and student responses to STEM-based inquiry learning.

Results about Students' Critical Thinking Skills

In this study, the results of the critical thinking skills test were measured on each indicator of students' critical thinking. The results of the paired t-test show that there is an effect of using a STEM-based inquiry learning package to increasing critical thinking skills as follows:

Table 2.

The Value of Critical Thinking Skills' Indicator (CTSI) at VIII A (n = 28)

CTSI	Pretest		Posttest		t score	Sig.
	M	SD	M	SD		
Basic clarification	2,82	1,827	20,82	1,982	-33,217	0,00
Decision	2,36	1,569	13,00	1,656	-53,049	0,00
Inference	2,54	1,551	13,18	1,744	-24,183	0,00
Advanced clarification	3,32	1,765	21,04	1,856	-45,675	0,00
Supposition and integration	2,54	1,503	13,18	1,701	-25,623	0,00

Tabel 3.

The Value of Critical Thinking Skill's Indicator (CTSI) at VIII B (n = 28)

CTSI	Pretest		Posttest		t score	Sig.
	M	SD	M	SD		
Basic clarification	2,79	1,833	20,79	1,853	-34,316	0,00
Decision	2,32	1,588	13,04	1,598	-52,311	0,00
Inference	2,54	1,551	13,14	1,693	-24,416	0,00
Advanced clarification	3,29	1,718	21,07	1,864	-44,883	0,00
Supposition and integration	2,50	1,528	13,25	1,735	-25,048	0,00

Tabel 4.

The Value of Critical Thinking Skill's Indicator (CTSI) at VIII C (n = 28)

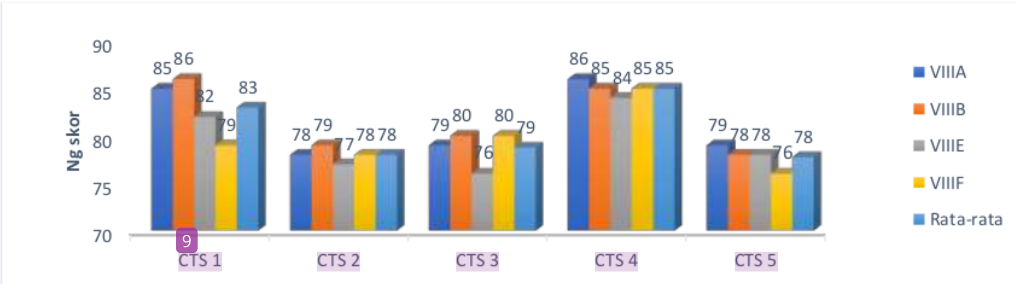
CTSI	Pretest		Posttest		t score	Sig.
	M	SD	M	SD		
Basic clarification	2,86	1,758	20,32	1,765	-39,731	0,00
Decision	2,32	1,588	12,86	1,380	-53,826	0,00
Inference	2,54	1,551	12,75	1,506	-29,886	0,00
Advanced clarification	3,25	1,713	20,75	1,713	-47,411	0,00
Supposition and integration	2,50	1,528	13,04	1,551	-24,574	0,00

Tabel 5.

The Value of Critical Thinking Skill's Indicator (CTSI) at VIII D (n = 28)

CTSI	Pretest		Posttest		t score	Sig.
	M	SD	M	SD		
Basic clarification	3,14	1,758	19,68	1,765	-99,299	0,00
Decision	2,32	1,588	13,04	1,551	-43,571	0,00
Inference	2,50	1,528	13,25	1,713	-58,822	0,00
Advanced clarification	3,32	1,765	20,82	1,362	-100,331	0,00
Supposition and integration	2,54	1,551	12,75	1,713	-37,968	0,00

Table 2-5 shows a significant increase in each indicator of critical thinking skills based on the mean pretest and posttest scores, besides it shows that the significance value of students' critical thinking skills is 0.00 < 0.05. Based on this significance value, it can be concluded that H1 is accepted, so there is a significant difference in students' critical thinking skills before and after learning with STEM-based inquiry learning. The increase of critical thinking skills based on the Ng score is the high category. The following figure llustrates the Ng score in each indicator of students' critical thinking skills:



Note: CTSI 1 (basic clarification); CTSI 2 (decision); CTSI 3 (inference); CTSI 4 (advanced clarification); CTSI 5 (supposition and integration)

Figure 2.
N-gain Score of Critical Thinking Skill's Indicator

Students' Responses

Student responses are student responses to the learning process using STEM-based inquiry learning packages on simple machine materials that have been developed previously at the end of learning. This questionnaire contains 15 questions about student responses to the learning that has been carried out. The results of the student response questionnaire showed very good criteria for STEM-based inquiry learning, as follows:

Table 6.
Student Response Questionnaire Results (n = 112)

No.	Statement	Percentage of Students Agree				Mean
		VIIIA	VIIIB	VIIIC	VIIID	
I	**Recency of learning**					
1.	Studying science by inquiry	71	76	82	82	78
2.	Hear the term STEM	79	76	76	79	77
3.	Studying science with STEM	79	89	89	86	86
II	**Interest in learning**					
1.	Learning condition	86	100	89	89	91
2.	Apply the concept in life	93	89	86	89	89
III	**Motivation**					
1.	Motivation to learn	93	93	93	86	91
2.	Motivation for observations and experiments	76	82	82	86	81
3.	Motivation to critical thinking	82	86	96	82	86
4.	Motivation to discussion	89	86	82	96	88
5.	Be confident in presenting the results of the discussion	86	93	82	89	87
IV	**Easily to learn concepts**					
1.	Associating material with life	86	89	86	89	87
2.	Understand the material	79	89	86	76	82
3.	Integrated STEM' aspects	93	96	89	86	91
4.	Obtain meaningfull learning	96	93	92	93	93
V	**Learning Expectation**					
1.	STEM based inquiry learning in other science materials	93	96	96	96	**95**

Discussion and Conclussion

Students' Critical Thinking Skill

The results of the critical thinking test show that each critical thinking indicator has increased in a high category with STEM-based inquiry learning. This is in line with the opinion of Stohlmann et al. (2012) that STEM can improve critical thinking skills through learning experiences. Byker et al. (2017) explained that inquiry activities improve students' critical thinking skills. In principle, inquiry learning can help students think critically (Erman & Sari, 2019; Erman et al., 2018) because it requires students to support and formulate questions or problems and answer questions through scientific activities (Šorgo et al, 2018). Viorel and Viorel (2015) state that scientific thinking aims to achieve critical thinking skills. STEM-based inquiry learning activities are designed to develop students' critical thinking skills. The insertion of each aspect of science, technology, engineering, and mathematics with the 5M inquiry stage in learning can construct students' knowledge in thinking.

Students are trained in solving problems according to the indicators of students' critical thinking skills. STEM is not only a learning approach but is a necessity to improve the quality of education. (Sujeewa et al., 2017). Learning with STEM is a necessity in the education of the highest quality. The analysis of the different test results of the critical thinking skills test shows that there are significant differences in the results and students' critical thinking skills before and after learning with STEM-based inquiry learning. This is in line with the opinion of Beers (2011) that STEM is an effort for students can find innovative solutions to the problems faced which consist of 4C, namely creativity, critical thinking, collaboration, and communication. Students are invited to solve problems in everyday life with reason and get meaningful learning.

Indicators of students' critical thinking skills are well developed in student activities while participating in STEM-based inquiry learning on simple machine (lever) materials. In the basic clarification indicator, for example identifying the type of lever based on the location of the fulcrum, PowerPoint, and load point; explain the working principle and the mechanical advantages factor obtained by the PhET simulation balancing-act activity; as well as explaining the role of the lever in the excavator's work. In the decision indicator, for example, the activity of determining the choices that must be made when several options are selected along with reasons. In the inference indicator, for example by concluding actions taken based on data and graphics along with the reasons. In the advanced clarification indicator, for example by mentioning daily equipment that applies a lever based on the type and reason; identify aspects of STEM in learning excavators. In the supposition and integration indicator, for example by analyzing mechanical advantages based on the load point on the use of a lever; find or design a technology tool that has a lever principle.

Learning activities can train students' critical thinking skills well. Maulucci et al. (2014) stated that STEM can develop students' abilities through inquiry, collaboration, and technology insertion in their learning. Borich and Ong (2006) stated that the inquiry learning orientation concerns the student's ability to solve a problem so that it focuses on students' critical thinking and on developing students' intellectual abilities. Students are trained and accustomed to critical thinking in the learning process. Figure 2 shows students experienced a high increase in each critical thinking indicator test. This is in line with Gnagey (2016) that STEM learning can increase student learning achievement. Becker and Kyungsuk (2011) stated that STEM has a positive effect on improving learning outcomes.

Students' Responses

Most of the students gave positive statements about the STEM-based inquiry learning tool. Student responses to the novelty of learning, interest, motivation, ease of learning concepts, and expectations in other science learning are very good criteria. Students are directly involved to apply the concepts (Burrows & Slater, 2015) they learn in their daily lives. This is in line with the opinion of Ghaemi (2017) that inquiry learning involves students in a real context in everyday life. Students feel more motivated (Tillman, An, Cohen, Kjellstrom & Boren, 2014) to learn, conduct experiments, think critically, discuss and be more active in learning activities using STEM-based inquiry.

Peters (2010) states that the learning environment formed by students who learn actively makes meaningful learning. Students understand and relate the material to everyday life, integrate aspects of STEM, and obtain meaningful learning (Stohlmann, Moore & Roehrig, 2012). According to David Ausubel's learning theory (meaningful learning) that learning will be more meaningful if the concepts to be taught are associated with concepts that have been learned by students. STEM-based inquiry learning is group learning which has been shown to get very good responses from students. In line with the principles of learning in Vygotsky's theory (Slavin, 2011) that social interactions can trigger students' cognitive development. Through their study groups, students can discuss and exchange opinions. STEM encourages group interaction in collaboration which can help in critical thinking. Students also hope that STEM-based inquiry learning can be implemented in other science materials. STEM encourages group interaction in collaboration which can help in critical thinking (Lee et al., 2015).

Based on the research results, it can be concluded that STEM-based inquiry learning packages are effective in improving students' critical thinking skills. Analysis of the paired t-test shows that there are differences in the results of students' critical thinking skills with STEM-based inquiry learning. This is also shown by the results of the increase in N-gain scores on students' critical thinking skills in the high category with the use of STEM-based inquiry learning packages. Student responses also showed a very good category for STEM-based inquiry learning.

Recommendations

Further study can be carried out for other materials in science, subject, moreover to levels of education. Moreover, further study can be carried out for development or improvement to other skill of the abilities 21st century which are very important in this life. Furthermore, STEM-based inquiry learning is effective to improve students' critical thinking skills.

Limitations of the Study

This study only focusses on the simple machine materials of lever taught for 2n grade of junior high school students. The focus of the study also to improve students' critical thinking skills with indicators of basic clarification, decision, inference, advanced clarification and supposition, and integration.

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