

Critical Thinking Ability and Student Learning Outcomes Through the STEM-5E (Bybee) Approach in Chemistry Learning About Molecular Shapes

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Abstract – This article is about research that aims to analyze students' critical thinking skills through the application of learning based on STEM-Model 5E (Bybee) in Molecular Chemistry Learning. This study was a pre-experimental research design with the design of one pretest-posttest group. The research subjects were 36 students of grade X MIPA IV SMA Negeri 5 in Padang. Data collection using test instruments that have been validated by experts. The results of the N-Gain analysis (g) showed that students' critical thinking skills reached 0.76 with high criteria and student learning outcomes reached 0.72 with high criteria.

Keywords: critical thinking skills, learning outcomes, STEM approach, 5E model (Bybee)

I. INTRODUCTION

The challenge of an educator is to provide an education system that creates opportunities for students to connect between knowledge and skills that are familiar in the revolutionary 4.0 era. STEM is a new learning in the world of education, which is an integration of four disciplines namely science, technology, engineering, and mathematics in an interdisciplinary approach and applied based on real world context and problem based learning. STEM learning includes the process of critical thinking, analysis, and collaboration where students bring together processes and concepts in a real-world context from science, technology, engineering, and mathematics to encourage the development of skills and competencies for college, career, and life.

In its implementation, STEM can be integrated with Project Based Learning (*PjBL*) - (*Lucas*), STEM (*Laboy-Rush*) and 5E (*Bybee*) learning models (*Zuhri*, 2019). popular because it can hone cognitive abilities, manipulative, design, utilize technology, and apply knowledge (*Capraro et al*, 2013; *White*, 20)

Learning Chemistry in Molecular Form is abstract material that cannot be seen with the eye because it is nano-sized. This can support students' understanding of the concept of molecular shapes which are often understood as memorizing concepts about the types of molecular shapes, molecular shape theory, and molecular shape formulas, but can design molecular shapes with materials in the surrounding environment. This means that through the STEM approach students do not just memorize concepts, but can better understand and comprehend scientific concepts and their relationship with technology, engineering, and mathematics in finding solutions to various problems in real life.

Therefore, to train and provide students' experiences in the STEM field with meaningful learning that can enhance their critical thinking knowledge and skills, learning is applied using the STEM approach with the 5E (*Bybee*) question model. This learning model designs learning where students will build and discover their own knowledge known as the Learning Cycle. Learning Cycle is a learning model based on inquiry and student-centered. The learning cycle learning model was initially

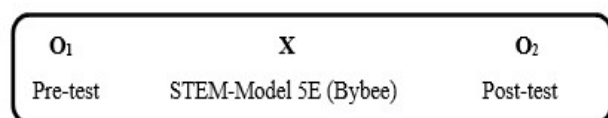
developed by Robert Karplus. This model is based on Piaget's theory with a constructivism approach.

Yogantari et al, (2014) argue that learning that characterizes the application of critical thinking skills is learning that provides opportunities for students to take an active role (student center), by encouraging students to be able to identify possible solutions, then be able to sort data from information obtained, then able to provide an opinion about the selected data, which is used to arrange temporary answers and finally able to provide the possibility of solving the problem.

II. RESEARCH METHOD

The study was conducted in the 2019/2020 school year at SMA Negeri 5 Padang, West Sumatra, with 36 students of Class X MIPA 4 research subjects. The research

design used in the study was one group pretest-posttest design (Sugiyono, 2016: 73). In this study subjects were given treatment in the form of STEM-model 5E (Bybee) (X sign). Before and after treatment is given, subjects are given written tests related to critical thinking questions and learning outcome questions (O mark). The research design pattern can be illustrated as shown in Picture 1.



Picture 1. Design Research Group Pretest-Posttest Design

Information :

- O₁ : pretest before the treatment is given
- O₂ : final test (posttest) after treatment is given
- X : treatment of the experimental group that is based on learning STEM-Model 5E (Bybee)

This research uses data collection techniques in the form of pretest test results before applying STEM-Model 5E (Bybee) and posttest learning after learning STEM-Model 5E (Bybee) as a matter of critical thinking and a matter of learning outcomes that have been declared valid by 3 expert lecturers and 2 teachers field of study with a validity result of 0.84 and critical thinking skills are measured based on Bloom's taxonomy starting from C4 to C6, while critical thinking skills are measured based on critical thinking indicators presented by Ernisa (1985) as presented in Table 1. Problem learning outcomes of students measured based on indicators of achievement of material competence in molecular shape based on Bloom's taxonomy starting from C1 to C5 which have been tested by analyzing the validity, replicability, difficulty level and different power of the questions. Mastery is achieved if the value obtained by students ≥ 80 (KKM Chemistry)

Critical thinking skills and student learning outcomes were analyzed by N-Gain (g) analysis through the answers of the pretest and posttest results by calculating the scores of each question indicator. The interpretation criteria for N-Gain (g) are presented in Table 2.

Table 1 Integration of STEM in Learning Chemistry of Class X Molecular Shapes with Critical Thinking Ability Indicators

N0	STEM	Indicators of Critical Thinking	indicator of exam questions
(1)	(2)	(3)	(4)
1 <i>Science</i>	Identify the molecular forms whether there are characteristics of the molecular shapes of a compound by literacy from various literatures	give out basic clarification - Focusing problems, - Analyze arguments, - Ask questions and answer questions.	1. Identifying with respect to the molecular forms of a compound. 2. Comparing molecular geometric shapes. 3. Explain what influences molecular shape
	The shape of a molecule is related to the position of the atoms in a molecule	<i>Build basic skills</i> The ability to give reasons	4. Explain why different molecular shapes
2 <i>Teknology</i>		<i>Determine an action</i>	

	as the application of science.	• Reveal the problem	5. Why do molecular shapes have different angles?
	• Observe technology that can make molecular shapes through computer applications (http://molview.org/)		
	• Designing molecular shapes models in three dimensions.	• Choose criteria to consider possible solutions	6. Can determine the central atom of a compound and determine the number of lone pairs surrounding the central atom
	• Conduct experiments using plasticine and sticks to make 3-dimensional molecular models		
3	Engineering As Engineering Science	• Making initial clarifications, making further clarifications.	7. Can describe the molecular structure of a molecule
	• Solve problems by providing solutions regarding the technology of making molecular shapes.		
	• Making three-dimensional molecular shape models that function as learning media		
4	Mathematics	• Make initial clarifications, make further clarifications, express opinions, and make conclusions	8. Apply the electron pair equation to determine the type of a molecule
	• Identifying differences in molecular shapes based on PEI and PEB from a molecule and VSEPR theory		

Table 2. N-Gain Interpretation Criteria

<i>N-Gain</i>	Interpretation Criteria
$N\text{-gain} > 0,7$	high
$0,3 \leq N\text{-gain} \leq 0,7$	medium
$N\text{-gain} < 0,3$	low

III. RESULTS

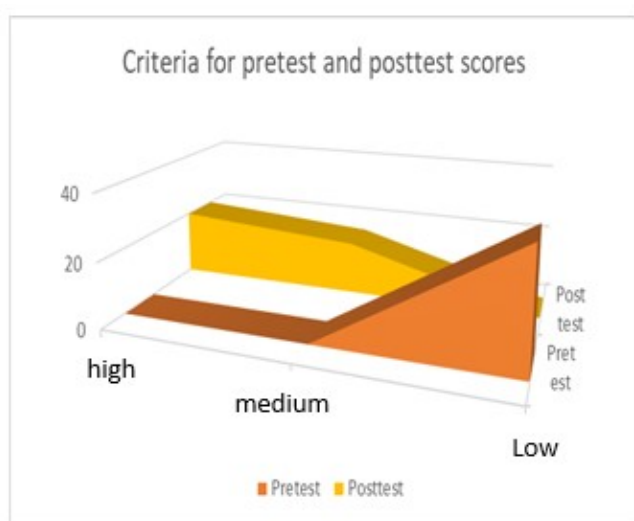
A. Description of research

In conducting this research, STEM-Model 5E (*Bybee*) is applied following the syntax of inquiry-based learning in general, namely: (1) preparation, (2) exploration, (3) explanation, (4) elaboration, (5) evaluation (*Bybee* , 2006). These four aspects of STEM take part in each step of learning (*Torlakson*, 2014). In molecular shape learning, the four aspects are implemented as cognitive abilities, skills in designing, assembling and using the tools and applications that are assigned, and communicating them. Understanding of concepts in STEM subjects can be obtained through complex problem solving (*Hickey* 2014). Therefore, in the learning process, the teacher guides students in small groups to develop various solutions to the problems given, encourage collaborative learning and strengthen critical thinking, creative and communication skills.

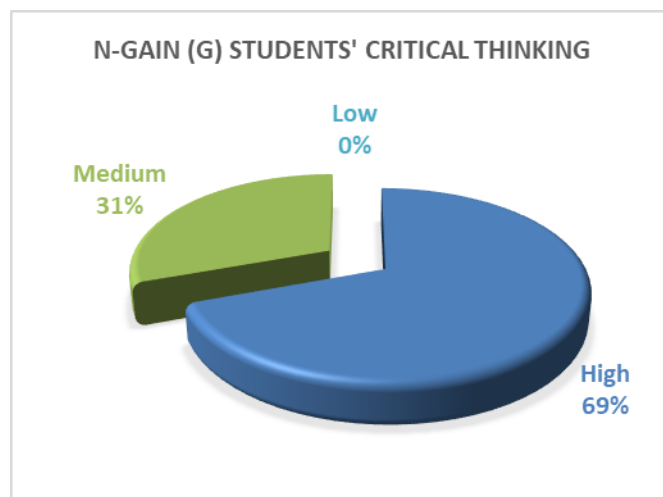
Students are divided into 6 groups with 6 members. Each group was given the task of designing a molecular shape model of a compound by looking at molview applications and making it in 3-dimensional shapes using plasticine and sticks. Each group gets two different compounds each group and given the opportunity to discuss solving problems related to the shape of the molecule, the type of molecule, determine the central atom and the bonding atom, and the repulsion theory of binding electron pairs. By following the instructions in LKPD that are associated with STEM-Model 5E (*Bybee*) and have been validated by expert lecturers. During the learning process, students are trained to be more active in finding answers to each given problem, more critical in responding to a problem, faster in digging information, more confident in displaying their work, and more effective in providing solutions to each problem encountered.

B. Results of Analysis of Critical Thinking of Students

Based on the descriptive analysis that has been done, it is found that the average value of students' critical thinking tests before and after carrying out chemistry learning activities based on STEM-Model 5E (*Bybee*). The average critical thinking ability of students before the implementation of learning activities in the form of molecular shapes with the STEM-Model 5E (*Bybee*) approach is in the low category and after the implementation of learning the shape of the molecules with the STEM-Model 5E (*Bybee*) approach is high is presented in Picture 2. While To see the effect of applying learning with the STEM-Model 5E (*Bybee*) approach, you can see the results of the N-Gain (g) analysis presented in Picture 3.



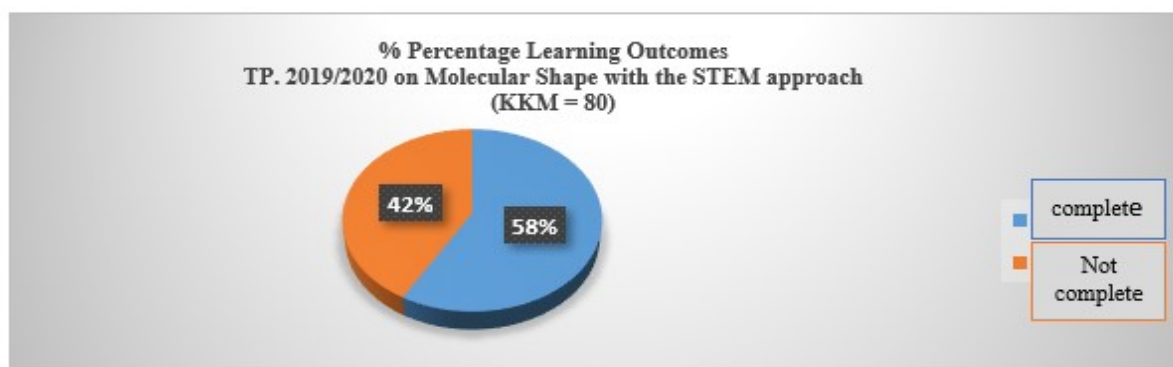
Picture 2. Graph Analysis of the criterion values of students' critical thinking pretest



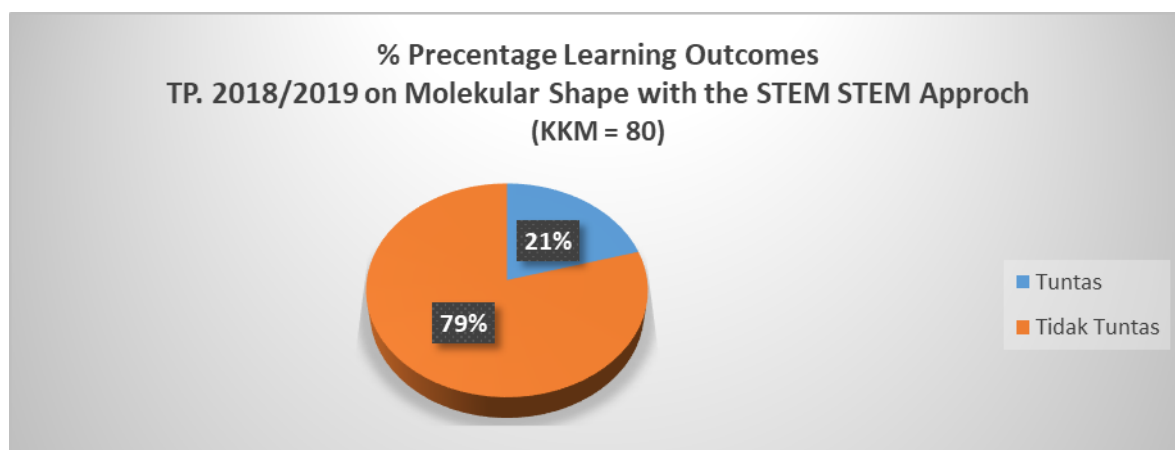
Picture 3. Percentage of Students' Critical Thinking Ability

C. Results of Analysis of Student Learning Outcomes

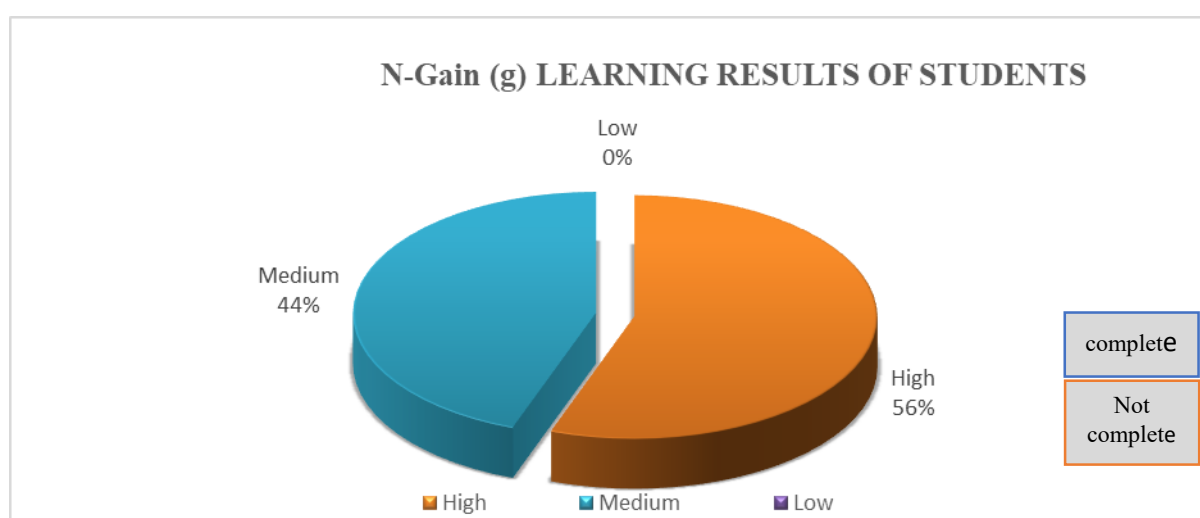
In line with the test of students' critical thinking skills, a learning achievement test is conducted, the average value of a student's learning achievement test before and after carrying out a chemical learning activity based on STEM-Model 5E (*Bybee*). Before carrying out the learning activities of the molecular shape with the STEM-Model 5E (*Bybee*) approach is in the incomplete category and after the implementation of the molecular shape learning with the STEM-Model 5E (*Bybee*) approach is complete and is presented in Picture 4. Compared with the percentage of student learning outcomes on the molecular shape material in the 2018/2019 school year using conventional approaches or lecture methods the results of observations show distress is presented in Picture 5. While the great influence of learning with the STEM approach can be seen from the value of N-Gain (g) student learning outcomes such as presented in Picture 6.



Picture 4 Percentage Learning Outcomes of TP Students. 2019/2020



Picture 5 Percentage Learning Outcomes of TP Students. 2018/2019



Picture 6 N-Gain (g) Student Learning Outcomes

IV. DISCUSSION

Critical thinking is rational thinking in assessing things. Before making a decision or taking an action, gathering as much information as possible about that something. The ability to think critically in the cognitive realm, in this study used a reasoned test of 8 questions for the pretest and posttest. The description test requires students to give the right reasons for giving answers. This research was conducted pretest before the implementation of learning based on STEM-Model 5E (*Bybee*) on the learning of molecular chemistry and posttest afterwards. This is done to see the progress in learning based on STEM-Model 5E (*Bybee*). Pretest which is 8 questions that have been validated and at the

end of the meeting a posttest is held which includes critical thinking aspects on the learning of molecular chemistry taught.

Enis groups critical thinking skills into five aspects, namely providing basic clarification, making the basis of a decision (the bases for a decision), making conclusions (inference), providing advanced clarification and managing strategies and tactics (strategy and tactics). Each aspect is divided into several indicators as shown in table 2 (Ennis, 1990: 68-69).

General characteristics of critical thinking are seeing things from various perspectives and dimensions, open to change and innovation, seeing things with prejudiced thinking, open-minded, analytical thinking and paying

attention to details of something (Birgili, 2015: 74). There are four areas of critical thinking skills as follows: (1). Effective reasoning. Different types of reasoning (inductive, deductive) that suit the situation are used. (2) Using a system of thought. Analyze how parts of a system interact with each other. (3) Make judgments and decisions: a). Analyze and evaluate evidence, opinions, demands and assumptions effectively. b). Analyze and evaluate the main alternative viewpoints. c). Synthesize and make connections between information and opinions. d). Interpreting information and drawing conclusions based on the best analysis e). Critically think about experiences and learning processes (4) Solve problems a). Solve various types of problems b). Identifying and asking significant questions clarifies various points of view and leads to better solutions.

The ability to think critically has reached a stage that characterizes it, that is, knowing the problem comprehensively, finding ways to solve the problem, gathering the necessary data, issuing opinions, making solutions to problems and conducting evaluations to the answers obtained.

Critical thinking is learning that uses reflective and productive thinking in discussing issues or problems by involving evidence giving. Critical thinking can also produce a decision or consideration that is processed logically in solving a problem (Nurasiah et al, 2015). Critical thinking can also be interpreted as a thoughtful procession that functions to identify problems until they find a solution to the problem.

Seeing the results shown in Figure 2 and Figure 3 prove that through the application of STEM-Model 5E (Bybee) in learning can affect the students' critical thinking skills, this is in accordance with the characteristics of STEM-Model 5E-based education (Bybee) to shape human resources (HR) able to reason and think critically, logically, and systematically so that later it will be able to face global challenges. STEM-Model 5E (Bybee) refers to the ability of individuals to apply an understanding of how intense competition works in the real world which requires four interrelated prayers. In the mathematics domain, the impact on learning with an embedded approach promises to gain knowledge in the fields of technology and engineering, (Honey in Nessa, 2017: 3)

Context in primary and secondary education, STEM education aims to develop students who are STEM

literate, (Bybee, 2013: 5) who have: (a). Knowledge, attitudes, and skills to identify questions and problems in their life situations, explain natural phenomena, design, and draw conclusions based on evidence regarding issues related to STEM; (b). Understanding the characteristics of STEM discipline features as forms of knowledge, inquiry, and design initiated by humans; (c) Awareness of how STEM disciplines shape the material, intellectual and cultural environment; (d). Want to be involved in the study of issues related to STEM as a constructive, caring, and reflective citizen by using scientific, technological, engineering, and mathematical ideas.

In implementing STEM-Model 5E (Bybee) students are invited to do meaningful learning to understand a concept. Students are invited to explore through a group activity, discussing so students are actively involved in the process. This fosters students to think critically, creatively, analytically, and improve higher order thinking skills (Capraro & Slough, 2013). These results are in line with research Nailul Khoiriyah Research, University of Lampung Students 2018 challenge *'Implementation of STEM Learning Approach to improve critical thinking skills of high school students in Sound Wave material '*, with the results of the study showing that the average value of N-Gain in the experimental class was 0,63 and the control class were 0.35 with the medium category, and the significance value of the Paired Sample T-Test test was 0,000 which means that the implementation of the STEM learning approach was able to improve students' critical thinking skills.

STEM is an approach that is formed based on a combination of scientific disciplines namely science, technology, engineering, and mathematics. Collaboration in learning, STEM will help students to collect and analyze and solve problems that occur and be able to understand the relationship between a problem with other problems. STEM education is meaningless when it only strengthens practical education in STEM fields separately, but develops an educational approach that integrates science, technology, engineering, and mathematics by focusing the educational process on solving real problems in daily life and professional life, (NRC , 2014: 44)

Learning with the STEM approach in this study focuses on its ability to improve critical thinking skills. Critical thinking is thinking that is always curious about the information available to reach a deep understanding. As stated in the limitation of research, critical thinking

skills in this study use four aspects of Facione (2011), namely interpretation, analysis, inference, and evaluation of the six aspects coupled with explanation and self-regulation. The aspect of critical thinking skills expressed by Facione is the generally accepted aspect, meaning that it can apply to every subject as well as every indicator used to know each of these aspects. In addition, someone who is said to think critically does not have to fulfill all aspects of critical thinking as critical thinking abilities as cognitive abilities. So to see the ability to think critically a person may be chosen one of several aspects with the focus of the discipline to be studied.

Picture 4 and 5 show that the percentage of mastery learning outcomes experienced an increase from the previous year that did not use the STEM approach, which reached 58% complete compared to the previous year only 21% completeness. This shows that the application of STEM-Model 5E (Bybee) is very suitable for improving students' understanding of concepts in the learning of molecular chemistry. The 21st century is a century of rapid scientific and technological development. Communities globally utilize technology products in their daily lives to facilitate work and improve their quality of life. Various technology products have also been utilized by students, both from the simplest form to the most sophisticated to facilitate them in the learning process. Not only limited to utilizing technology, students are also expected to be able to create new technology with their creativity.

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According to Syahi (2011: 1) in his paper, the assessment of learning outcomes for students participating in educational activities is one of the important factors, because of the assessment of learning outcomes, the results of the study will be seen by the correlation between the success of the educational

institution (school) in examining the students who are important. The existence of assessment of learning outcomes will also provide a descriptive picture of the achievement of learning outcomes of students, either individually or as a whole. Aside from the categories of learning outcomes, there are some influences that make assessment factors from learning outcomes of students, namely intelligence factors, friends, teaching factors, and environmental factors in which the students participate.

V. CONCLUSION

By looking at the results of research and discussion that has been done, the conclusions that can be drawn from this study are as follows :

There was a significant increase in learning activities based on STEM-Model 5E (Bybee) in the learning of molecular chemistry in class X MIPA 4 of SMA Negeri 5 Padang on increasing critical thinking skills with normalized N-Gain (g) scores of 0.76 highly qualified.

There is a significant effect of STEM-Model 5E (Bybee) based learning activities on molecular shape chemistry learning with lesson study in MIPA 4 class X SMA Negeri 5 Padang on improving student learning outcomes with normalized N-Gain (g) scores of 0.72 qualified high.

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