Original Paper

The Involvement of Science, Technology, Engineering, and Mathematics (STEM) Learning in an APOS Analysis of Students' Mathematical Understanding

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Abstract

This article was reported as a research that involved Science, Technology, Engineering and Mathematics (STEM) Learning by using APOS theory framework to investigate Students' Mathematical Understanding of sine rule and cosine rule concept. Sine rule and cosine rule concepts are taught to eleven-grade senior high school students in Indonesia. Students' responses to five trigonometric problems involving sine rule and cosine rule were analyzed through this article. This study has confirmed that sine rule and cosine rule concept can be understood through STEM learning engagement because it has enabled students to obtain the appropriate mental structure at the action, process, object and schema levels. However, sustainable development needs to be done to improve mathematics learning that can build mental structures needed by students to understand mathematical concepts.

Keywords

STEM Learning, APOS Theory, Mathematical Understanding

1. Introduction

In grade 11 Indonesian students were asked to master Trigonometry material about sine rule, cosine rule and triangle area. This can be seen in the learning objectives that require students to learn trigonometric material, 1) describe and analyze the sine rule and cosine rule and apply them to solve problems; 2) design and propose a real problem and solve it by applying sine rule and cosine rule. There are many difficulties faced by students in understanding the concept of sine and cosine rules.

This is because students often get these rules without going through the right process from the teacher. Even though if the teacher wants to carry out various strategies in the learning process, students can be helped to better understand the concept. These strategies are the teacher's responsibility to be understood and implemented (Kivkovich, 2015).

The fact that mathematical problems, including Trigonometric problems, become complicated and more abstract, discourage some students from finding solutions to all the mathematical problems in a course. To overcome this problem, mathematical education researchers have carried out research. According to Yilmazer and Keklikci (2015), based on research findings, two of the conclusions are: (1) The positive impact on learning success through the use of games and models; (2) The application of new methods during instruction that can increase success. The use of media will have a positive effect on teaching mathematics. The findings of Krishnasamy et al.'s (2014) research indicates that between facilities and problems encountered in the use of media, there is a positive relationship.

In addition to various devices or media, mathematics learning also requires the right approach to overcome students' learning difficulties and misconceptions. Problem-Based Learning method could help reduce students' mathematical misunderstanding and mathematical misconceptions so that it affects their performance and their attitude toward mathematics (Kazemi & Ghoraishi, 2012). According to Zengin et al. (2012), a supplement to constructivist instruction like computer-assisted instruction is more effective than the constructivist method.

Finally, the teacher's ability to ask questions to students in the learning process needs attention. Udi and Star (2011) stated that an understanding of the importance of "good question-asking skills" in mathematics must be possessed by the teacher. The creation of various situations through the questions posed must be done to relate to the problem being learned as well as the introduction of situations that require these skills, in order to immediately lead to the situation.

Thus, the use of learning media that is supported by a good learning process accompanied by the teacher's ability to provide the above questions, can be conditioned in learning that involves STEM learning in it. To obtain data about the success students in the learning process, we need an understanding of the learning process that occurs in students during learning.

The research questions that will be asked are:

- How to show students' mathematical concept understanding of sine and cosine rule through APOS theory analysis?

- How is the students' mathematical concept understanding of sine and cosine rules based on the APOS analysis that obtains learning by involving STEM learning?

1.1 APOS and ACE Teaching Cycle Involving STEM Learning

Pedagogical strategies in the form of ACE teaching cycle have components consisting of: (A) Activities; (C) Classroom Discussion; and (E) Exercises. For the activity component, students work cooperatively in teams on tasks designed to help them make the mental construction suggested by the genetic decomposition. A genetic decomposition of a concept is a set of structured mental constructs that might

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be able to describe the development of concepts in individual mind (Asiala et al.: 1997). The Classroom Discussion is an activity that occurs when students work on paper and pencil tasks that built on the lab activities that are completed in the activity phase given by the instructor, which involves small group discussions and instructors. Exercises are activities in the form of giving fairly standard problems with the aim of strengthening computer activities that are replaced by STEM learning activities and classroom discussion. These exercises help to support the development of further mental constructs suggested by the genetic decomposition. They can also direct students to consider related mathematical ideas and to be able to apply what they have learned (Arnon et al., 2013).

The genetic decomposition as a structured set of mental, affects every component of the ACE Teaching Cycle. This means that genetic decomposition is built on what students might need when they want to perform on mental objects that already exist and then include explanations of how actions are interiorized into the processes within them in the Teaching Cycle of ACE. The Actions are designed by the teacher through its description to make each component of the Teaching Cycle of ACE applicable by the students. These activities are phases which are the main subject of classroom discussion. Meanwhile, classroom discussion provides opportunities for students to reflect on activities. The main purpose of the exercise phase is to strengthen the mental constructions that students make as they work in the activity phase and participate in the classroom discussion phase.

STEM learning are activities that replaces computer activities in what Dubinsky formulated as supporting the activation of mental mechanisms in the form of interiorization and encapsulation. Therefore, these activities will lead to the development of mental structures in the form of Process and Object which are the basis for the formation of mathematical concepts (Arnon et al., 2013; and Bybee, 2010). The STEM learning approach involved in this research is a mathematics lesson plan using mathematical kit which is designed to make students engage in the Actions phase as part of APOS theory.

1.2 APOS Theory in The Sine and Cosine Rule Concepts

To Build the APOS mental structure consisting of action, process, object, and schema, Dubinsky and Weller stated that the main mental mechanism are Interiorization and encapsulation (Arnon et al., 2013). Other types are part of what is called reflective abstraction consisting of reversal, coordination and generalization.

Assimilation of knowledge and mechanisms used by Piaget in his work known as accommodation, are related to the APOS idea of generalization (Arnon et al., 2013; and Maharaj, 2010). All processes in APOS related to mathematics learning material sine rule and cosine rule are as follows:

Action, in the case of sine rule and cosine rule concept is one of the stages of learning in APOS theory that allows students to get an explicit expression in an effort to think of sine rule concept: $\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$ and cosine rule: $a^2 = b^2 + c^2 + bc \cos\angle A$ in an ABC triangle. In this Action stage, students can do little more than substitute for the variables a, b, and c and manipulate it to find the area of the triangle, for example, is considered to have an action stage of understanding sine rule and cosine

rule.

Process, in the case of sine rule and cosine rule concepts includes the action of computing the length of one side from three sides or one angle from three angles in any triangle. This action stage is interiorized into a Process stage when students can explain in general how to find the length of this side by providing the lengths of the other two sides or measuring the other two angles and understanding ideas about what they need to know before computing the length of one side or measure of one angle.

Object, in the case of sine rule and cosine rule concept includes the encapsulation that allows students to apply the two rules such as compute the area of any triangle.

Schema in the case of sine rule and cosine rule concept may be found when students understand about the determination of the area of any triangle and must be considered to the following: the formula of the area of the triangle, the formula of trigonometric function, the area of a parallelogram, etc.

The only explanation offered by APOS analysis is about the description of thoughts that students might have. What actually happens in students' minds is not described because it might be impossible to know. APOS analysis is mainly used to show possible pedagogical strategies (Maharaj, 2010; and Mudrikah, 2016).

1.3 Science, Technology, Engineering, and Mathematics (STEM) Learning

In many of today's mathematics classrooms, according to Riley et al. (2013) when viewed from students' engagement, tend to use content and pedagogy that is based on reading texts and memorizing facts. The things that can arouse and challenge students' minds tend to be a little bit sacred. Students only have few opportunities to experiment directly and connect concepts taught in class with their daily lives.

Research on integrated mathematics teaching and sciences has provided a good basis for teaching that is integrated with STEM education (Stohlman, Moore, & Roehig, 2012; and Han, Capraro, & Capraro, 2015). Pang and Good (2000) state that teachers' understanding of subject matter is the main determinant of the successful integration of science and mathematics. Zemelman et al. (1998), when discussing about effective practices in STEM integration, list eleven recommendations on teaching mathematics as follows:

1) use manipulative materials;

2) cooperative group work;

3) discussion of mathematics;

4) questioning and making conjectures;

5) use justification of thinking;

6) writing about mathematics;

7) use a problem solving approach to instruction;

8) content integration;

9) use of calculators and computers

10) being a facilitator of learning;

11)   assesing learning as an integral part of instruction.

Stohlmann, Moore and Roehrig (2012) stated that for the future success of students, the effective application of STEM education is very important. To achieve this goal of success, it is necessary to do the preparation and teachers' support of integrated STEM education. The STEM model for teaching integrated STEM education is described in Table 1 below:

Table 1. The STEM Model for Teaching Integrated STEM Education, which is Considered

Support

- Partner with university or nearby school
- Participate in professional development activities
- Teacher time to collaborate
- Training and contacts of curriculum company

Teaching

Lesson Planning

- Focus on connections
- Translation of representations
- Understand students' misconceptions
- Problem solving based
- Students centered
- Build on previous knowledge
- Focus on big ideas, concepts, or themes
- Integrate technology
- Real world and cultural relevancy

Classroom Practices

- Question posing and making conjectures
- Justifying thinking
- Writing for reflection
- Focus on pattern understanding
- Use assessment as part of instruction
- Cooperative learning
- Effective use of manipulatives
- Inquiry

Efficacy

- Content knowledge and pedagogical knowledge contribute to positive self-efficacy
- Commitment to STEM education is vital
- Planning and organization are critical

Materials

- Technology resources
- Broad view of technology
- Materials kits for activities
- Room space and storage for materials
- Tables for group work

As what Ostler stated (2012), to be able to provide more than an occasional and coincidental overlap of the topics of mathematics and science, obedience is needed in integrative STEM content in lesson

design. It provides a cyclic model for developing methods of learning STEM content that are deep, adaptable, and strategic. The STEM acronym represents hierarchy and cycles in building a conceptual understanding of how the STEM subjects are interactive and adaptable (Roberts, 2012; and Reeve, 2013).

2. Method

The participants were 35 grade eleven students of science at a senior high school Islamic boarding school in Indonesia. The students were studying sine and cosine rules with an activity sheet and mathematical kits. The aim of the activity sheet assisted by mathematical kits is to introduce students to the concepts of sine and cosine rules. These students attended the learning process to achieve the understanding of concepts and to gain the ability to solve problems.

The method used in this research was conducted the research of Maharaj (2010). Participants find the concepts of sine rule and cosine rule and types of problems, which are indicated to be relevant to the theoretical analysis of APOS mental structure. The stages of APOS Theory have explained the details of this mental structure. Thus, genetic decomposition can be detected as follows. At the action stage, students are confronted with the tasks that need the help of sine rule and cosine rule mathematical kits in doing them. When students construct mental processes for values a, b, and c in the sine and cosine rules and think in terms of inputs, which may not be determined, and the transformation of these inputs to produce many outputs, an understanding of the sine and cosine rules processes is appears. At the object stage, this series of tasks is seen by the students as totality so they become able to perform mental actions in the form of writing the length of triangle sides or measuring angles. In this stage, the process of understanding is encapsulated and converted to an object of the area of any triangle. At the schema stage, there is an organization of actions, processes, and objects which are linked into a coherent framework. Possible techniques for evaluating any triangle sides, the angles and area of a triangle, including daily problems about them, are covered in this framework.

The theoretical analysis of sine rule and cosine rule concepts and the types of problems that students must face, inform about teaching cycle of ACE involving STEM learning. In the 45-minutes learning session, the key question that students want to solve is what is the formula for the sine rule and the cosine rule and how to use these rules? Mathematical kits of sine rule and cosine rule are projected as devices that formulate student activities. Students reflect and work on each activity given in their group within the given time. They can freely discuss the tasks in their group to find the formulas. The students were observed about the way they work and how they face difficulties and address aspects that they think need further explanation when they engaged with the activities. Another 45-minutes was specifically used by students to conduct activities based on techniques related to find the length of one side and area of a triangle. Class activities and discussions end with the provision of exercises to be done at home. Students are asked to do homework exercises that are part of their tutorial requirements.

One week after the learning process, all 34 students were given multiple choice questions. The questions given to students consisted of 4 questions which could be related to the level of APOS mental structure. The four problems are the national exam questions whose choice of answers are modified so that the answers choosen can reflect the level of mental structure of students who make choices on the alternative answers given. Students were first asked to find solutions to each question to be written in the blank section on the answer paper then write their choices on multiple choice cards.

3. Results and Discussion

The analysis, findings and discussion represented related to each of the four questions with subheadings that describe the type of question are used as follow:

1)   Finding one side of any triangle that is known another two sides and one angle of it

2)   Finding the circumference of dodecagon

3)   Finding the length of a tetragon side by using sine rule and cosine rule concept.

4)   Finding the boat's distance traveled by cosine rule

3.1 Finding One Side of Any Triangle that is Known another Two Sides and One Angle of It

Let the *MAB* triangle with *AB* = 300 cm, the angle of *MAB* = 60° and angle of *ABM* = 75°. The length of *AM* = ... cm.

A. $150(1 + \sqrt{3})$ B. $150(\sqrt{2} - \sqrt{3})$ C. $150(1 + \sqrt{6})$

D. $75(1 + \sqrt{3})$ E. $75(\sqrt{2} + \sqrt{6})$

Table 2. Question 1 Analysis of Students' Choices (N = 35)

A^*	B	C	D	E	Omit index	Bad index
19	2	2	1	3	8	0
54.29%	5.71%	5.71%	2.86%	8.57%	31.43%	0%

Question 1 is about how to find the side length of a triangle after students can first find one of the angles of the triangle (angle *M*). Analysis of the questions in Table 2, by observing the total for option *B* shows that 2 students used the formula incorrectly adding the trigonometric function formula. The number of choices *C, D*, and *E* indicates that 6 students could have made a calculation error; and if this reason is accepted, their mental construction might only reach the level of object in APOS.

Table 2 also shows that 19 students choose the correct answer. This condition indicates that for the concept of sine rule, around 54,29% of students related to the context of genetic decomposition had mental construction that reach to the object level. Table 2 also shows that 8 students did not choose any answers. One reason for this condition after knowing what they did in their test was that they did not have any idea of how to solve the problem by using sine rule concept.

3.2 Finding the Circumference of a Dodecagon

The area of dodecagon is 192 cm^2. It circumference is ... cm.

A. $8\sqrt{2-\sqrt{3}}$ B. $96\sqrt{2-\sqrt{3}}$ C. $128 - 64\sqrt{3}$

D. $96(2-\sqrt{3})$ E. $96(\sqrt{2} - \sqrt{3})$

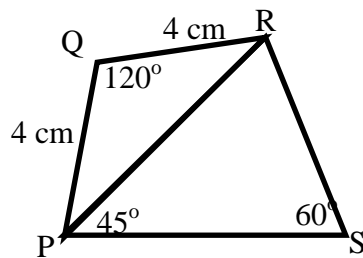**Table 3. Question 2, Analysis of Students' Choices (N = 35)**

A	B*	C	D	E	Omit index	Bad index
1	17	3	3	1	10	0
2.86%	48.57%	8.57%	8.57%	2.86%	28.57%	0%

Question 2 is based on the circumference of a dodecagon. Analysis of the problem in Table 3 by considering the total selector of answer *A* and *C* indicates that four students experienced an error in using the sine and the cosine rules. As for students who choose *D*, indicates that there were three students who could not continue to calculate the circumference of a dodecagon by calculating the length of it side. One student who chooses *E* shows that he or she made have a calculation errors and if this was accepted, his or her mental construction might function at the object level.

Table 3 also shows that 17 students choose the correct answer. This condition indicates that for the concept of cosine rule, around 48,57% of students related to the context of genetic decomposition had mental construction that reach to the object level. Table 3 also shows that 10 students did not choose any answers. One reason for this condition after knowing what they did in their test was that they did not have any idea of how to solve the problem by using cosine rule concept, even using the trigonometric principle in determining the area of triangle formula.

3.3 Finding the Length of a Tetragon Side by Using Sine Rule and Cosine Rule Concept

From the figure below, the length of RS is ... cm.

A. $4\sqrt{3}$ B. $\frac{16}{3}\sqrt{6}$ C. $2\sqrt{3}$ D.   12   E. $4\sqrt{2}$

Table 4. Question 3 Analysis of Students' Choices (N = 35)

A	B	C	D	E*	Omit index	Bad index
1	2	3	1	16	12	0
2.86%	5.71%	8.57%	2.86%	45.71%	34.29%	0%

Question 3 is based on the side of a tetragon. Analysis of the problem in Table 4 by considering the total selector of answer *A* indicates that one student feels quite satisfied by obtaining the results of an answer that uses cosine rule even though they have not been able to answer the questions asked. As for students who choose *B*, indicates that there were two students who use the uncorrected formula of sine rule. Three students who choose *C* and one student who choose *D* shows that they made have a calculation errors and if this was accepted, their mental construction might function at the object level. Table 4 also shows that 16 students choose the correct answer. This condition indicates that for the concept of sine rule and cosine rule, around 45,71% of students related to the context of genetic decomposition had mental construction that reach to the object level. Table 4 also shows that 12 students did not choose any answers. One reason for this condition after knowing what they did in their test was that they did not have any idea of how to solve the problem by using sine rule and cosine rule concept.

3.4 Finding the Boat's Distance Traveled by Cosine Rule

A boat starts moving from port *A* at 09.00 with direction 030 ° and arrives at port *B* after 2.5 hours of movement. At 14.00 the boat moved back from port *B* to port *C* by turning the bow 150 ° and arrived at port *C* at 19:00. If boat's average speed is 80 miles/hour. The boat's distance traveled from port *C* to port *A* is ... miles.

A. $200\sqrt{2}$ B. $200\sqrt{3}$ C. $200\sqrt{5 - 2\sqrt{3}}$)

D. $200\sqrt{5}$ E. 600

Table 5. Question 4 Analysis of Students' Choices (N = 35)

A	*B*[*]	*C*	*D*	*E*	Omit index	Bad index
1	12	1	1	2	16	0
2.86%	34.29%	2.86%	2.86%	5.71%	45.71%	0%

Question 4 is based on the daily problem of finding the boat's distance traveled by cosine rule concept. Analysis of the problem in Table 5 by considering the total selector of answer *A, C* and *D* indicate that three students made have a calculation error, and if this was accepted, their mental construction might function at the object level. As for students who choose *E*, indicates that there were two students who use the uncorrected formula of cosine rule. Table 5 also shows that 12 students choose the correct answer. This condition indicates that for the concept of cosine rule, around 34,29% of students related to the context of genetic decomposition had mental construction that reach to the object level. Table 5 also shows that 16 students did not choose any answers. One reason for this condition after knowing what they did in their test was that they did not have any idea of how to solve the problem by using cosine rule concept.

Table 6 below explains the summary of the four tables above. This table explains the potential for the

highest level of students' mental structure for four types of questions classified into four multiple choice questions. For example, This Table shows that for question 1, students' responses indicated that 37.14% of them had a level of mental structure at the level of action. For the same question, 17.14% of them have the potential to go to the process level. Meanwhile, 54.29% of them for question 1 have the potential to go to the level of schema. Explanations from Table 6 for question number one can be used to interpret other questions.

Table 6. Percentage of Response towards Highest Potential Levels According to Mental Structures

Type of Question	< Action Level	Action to Process	Object to Schema
1	37.14	17.14	54.29
2	40	8.57	51.43
3	37.15	5.71	57.14
4	51.42	-	48.58

4. Conclusion

The study has shown that the participants still had difficulty in solving the problem related to the use of sine and cosine rules. Although many of them obtain an appropriate mental structure at the level of action and process, for the level object and schema in the analysis of APOS theory, they still did not have appropriate mental structures. Even there are still many among students who have not been able to reach the level of action at all. Nevertheless, it appears that STEM learning assisted by mathematical kit along with student activity sheets were able to build mental structures at action and process levels.

While at the object and schema level, students still need to improve their understanding of other trigonometric materials such as trigonometric functions of an acute angle and of any angle, right triangle trigonometry, addition formulas and trigonometric identities. This is undeniable because the students' understanding of sine and cosine rules concept cannot stand alone, but tend to depend on their understanding of other trigonometric materials. To overcome this problem, the teacher should first believe in the students' prior mathematical abilities before implementing their learning approach. Related to the use of APOS theory analysis as a psychological analysis in revealing the students' mathematical understanding, it seems that teachers must have the ability to do this APOS Analysis.

This is in accordance with the statement Newcombe et al. (2009) about psychology as a broad scientific discipline that covers many areas of important research for the success of education in mathematics and science. According to Newcombe et.al (2009), Psychology along with cognitive science, neuroscience, computer science, and other fields, is a key scientific discipline in the effort to form new learning sciences that have interesting potential to provide insight into the nature of human learning and the best ways to improve it at all ages and in various disciplines.

5. Recommendations

The difficulty of participants in solving the trigonometric problems given to them arises because they have not been able to reach the level of objects and schemas in APOS theory. This clearly requires serious attention from teachers who teach mathematics. The teacher must pay more attention to the level of student achievement while studying mathematics. The learning process must also be able to measure the level of student achievement. Thus the right instruments are needed in an effort to measure the level of achievement. Understanding mathematical concepts is of course not only limited to the ability to solve routine mathematical problems. But also high order mathematical thinking ability must also be the main target in learning mathematics.

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