Performance of Undergraduate Students To Deal with STEM (Science, Technology, Engineering and Mathematics) Based Problems

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Abstract. The type of research carried out in this article is descriptive which aims to provide an overview of students' high-level thinking skills in solving STEM-based problems, especially Medan State University. The subjects in this study were 45 students in the first semester of the mathematics education study program. Data collection in this study was carried out by giving a pretest to students with 15 minutes and interviews. Interviews were conducted with the aim of obtaining information about how students solve the problems presented. The results of the pretest and interviews were used as material to answer the main problem in this study. In this case, the research findings suggest that the initial abilities of students generally have not been able to help them solve the STEM problems presented to them. In solving the problems given, some students tend to use trial and error methods, while others use descriptions in words or pictures.

Keywords: STEM, Students’ Performance, Undergraduate, Higher Education

1. Introduction

The world of modern education today has referred to the 21st century learning which emphasizes the ability to reason (reasoning) and literacy (literacy) more than mastery of material or an understanding of "content analysis" [1]. This means that education actors are required not only to have academic abilities, but also to be familiar with the problems and be able to apply this academic knowledge in finding solutions and determining solutions to these problems, including students. The application of knowledge obtained by students is based on their learning experiences while on campus [2]. The situation above indicates that there is a very close relationship between education discretion itself and how it is implemented on campus [3].

Based on these circumstances, [4] argued that the current implementation of education should basically be aimed at eliminating the gap that separates "theory" and "fact". This means, the purpose of implementing education must be able to make students able to combine "What they have learned on campus" and "How do they apply this knowledge" in solving problems. This kind of ability is called Higher Order Thinking Skills [5], which is commonly known as HOTS.

In general, the ability to reason and literacy are not just created in students. One possible way to develop these abilities is through the design of classroom learning activities [6]. Design activities that can not only explain the content but explain the relationship of this knowledge with other knowledge, such as Science, Technology, Engineering and Mathematics (STEM) [7]. Here, the STEM learning
design is meant to be an activity based on the phenomena around students that require them to think logically and at a high level in mathematics.

In mathematics, early learning that can make students think at a higher level (including reasoning and literacy) is found in the set and logic courses. This set and logic course is studied by students when they are in the first semester of lectures. However, the learning process generally takes place face-to-face and in one direction during this course of study. That is, learning is centered on lecturers as a source of information and knowledge. This can result in students' mathematical reasoning and literacy abilities not developing [8]. Students tend to listen to lecturers' explanations and not the meaning of these explanations. Therefore, research that aims to develop teaching materials based on Higher Order Thinking Skills (HOTS) with STEM learning is the main key.

According to [9] suggests that the initial ability (starting point) identifies natural knowledge and relevant skills including other background information on the characteristics of learners that he already had when he was about to start following a teaching program. In addition, [10] stated that early learning abilities can be said to be the knowledge or skills that students already possess so that they can follow the learning process of mathematics well.

In information about students' initial abilities in solving problems [11-12], it can help lecturers in designing learning activities that can support students' abilities in learning mathematics courses. For this reason, this research was conducted with the aim of exploring descriptively about students' initial reasoning abilities in solving problems about graphs in the Mathematics Department, Medan State University. Based on the research background above, the problem formulation discussed in this study is “How do undergraduate students deal with STEM-based problems?”.

2. Theoretical Framework

2.1. Reasoning skills in mathematics
Reasoning skills are one of the main components in Higher Order Thinking Skills (HOTS) which must be mastered by students as stipulated in the Education Development Plan in Indonesia to date. The need for students to master mathematical reasoning skills is seen as more important when they study Additional Mathematics, in particular, for analytic mathematics topics such as Sets and Logic. In the Higher Education Curriculum creative thinking, critical thinking and logical thinking skills, and higher order thinking skills are the main focus. The main focus of this curriculum is to cultivate Higher Order Thinking Skills (HOTS) among students, so that they can demonstrate their own abilities through reasoning skills [13]. This is basic knowledge about research as a scientific activity to find the truth and at the same time as a process of obtaining knowledge in mathematics.

Additional Mathematics is one of the analytical mathematical concepts that requires students to think before making decisions, with reasons to solve problems, and requires them to have a good level of conceptual understanding in doing work. Thus, reasoning skills must be incorporated into the learning process, to enable students to have their thinking skills triggered, ideas generated, thought control and good solutions achieved [14]. However, according to [15], after lecturers diversify their teaching and learning methods, students can master other mathematics subjects.

2.2. STEM-based learning
Science, Technology, Engineering and Mathematics (STEM) is a general curriculum that works on Science, Technology, Engineering and Mathematics education in learning that makes use of interdisciplinary knowledge and an applicable approach to problem solving. Over the past few decades, STEM education has focused on improving science and mathematics as integrated disciplines ([16-18]) and emphasizing technology ([19-20]). STEM is often taught apart from art, creativity, and design [16]. STEM education as an approach that explores teaching and learning between two or more subjects in schools [19]. STEM education is an attempt to combine several disciplines; technology, engineering, and mathematics into one class, unit, or lesson based on the relationship between the subject and real-world problems [8]. STEM is an extension of the Mathematical Engineering Science
Technology Science (STEM), by incorporating Art elements which are positive, rich and powerful elements in civilization and in many ways can take a decisive position.

2.3. Higher Order Thinking Skills
Experts define higher order thinking skills (HOTS) with different approaches and points of view. [5] argues that HOTS is difficult to define, but easily recognized by its characteristics. Furthermore, [6] revealed some of the characteristics of HOTS as follows: (1) non-algorithmic, meaning that action steps cannot be fully determined in advance; (2) tends to be complex, meaning that steps cannot be seen or predicted directly from a certain perspective; (3) often produces multiple solutions rather than a single solution; (4) involves disagreements (nuanced judgments) and different interpretations; (5) involves the application of various, sometimes conflicting, criteria; (6) often involves uncertainty; (7) involves self-regulation in thought processes; (8) involves imposing meaning, such as finding irregular structures; and (9) requires great effort. When examined closely, the general characteristics of HOTS above suggest the need for unusual thought processes or thinking that is more complex and still requires unusual effort.

Effective learning is expected not only to facilitate students to develop memorization skills, to understand concepts and their application, but also to facilitate students to be able to develop higher order thinking skills.

3. Methodology

3.1 Research Subject
Based on the curriculum in tertiary institutions, students will receive formal learning materials about advanced mathematics when they are in Higher Education [10]. Therefore, this research was conducted in the mathematics department, Medan State University, which is located in the city of Medan. During this research, 45 fourth semester students of the Mathematics Education Study Program were involved as research subjects. In addition, lecturers who implement this research are also included.

3.2. Data Collection
To get data about how students solve problems about graphs, data retrieval is done in various ways which in this case are called "Data Triangulation"[8,20]. This means that data is obtained through video recordings, worksheets (students' worksheets), interviews with students, and field notes. In this study, video recordings played an important role in recording the interview process and all activities during the teaching and learning process. During learning and teaching activities, all student work and activities are recorded for later analysis in the retrospective analysis stage. After the pretest was carried out, the student answer sheets were grouped based on similar answers or how to solve similar problems. For example, student answers by completing descriptively (word description) or the same error. After the answers are grouped, the next activity is to conduct interviews with students based on information obtained.

To get data about how students solve graph problems, interviews are carried out directly to students. In this preliminary conduct study, the interview is conducted basically with the aim of obtaining information on how students solve STEM-based problems. In this case, interviews were not conducted with all students; however, the interview process was carried out on some students whose answers needed to be explored. For example, students use pictures or tables in solving the problems presented. They are asked to explain the solving steps taken and how they get or draw conclusions to determine the solution to the graph problem. Meanwhile, field notes are used to obtain information about student activity that cannot be recorded by the recorder.
4. The Problems
During the pretest implementation, students were presented with three questions related to graphs. These questions are designed with the aim of obtaining data about how students use their initial reasoning skills in solving graph problems. Students are asked to complete the questions below.

1. Chandra Fills water into a 440 ml glass. The discharge of the dispenser tap when filling the glass is 15 ml / sec. Then add sugar to a glass filled with water. Then the sugar goes straight down to the bottom of the glass. However, when stirred for a while, the sugar form disappears and merges with water. How many minutes does it take to fill 35 glasses, each of which must be filled 3/4 full?

2. If you are appointed by the minister of transportation to design the form of a train that should be owned by the Indonesian people on the condition that it can move more quickly and economically...

| No | Part                                | Physical Reason                      |
|----|-------------------------------------|--------------------------------------|
| 1  | Replacing the bottom rail with superconducting magnets | Makes the train body float against the rails so there is no friction |
| 2  | Changed the front of the train to resemble a dolphin head | Increase train speed while moving |
| 3  | Using Magnets On Its Rail To Move Forward | Energy safety |
| 4  | Using a solenoid on the underside of the train | Change the poles on the magnets on the rails |
| 5  | Extending the front of the train | Reduces air resistance |

The exact reason is ...

3. In the morning Chandra went to the library to do his final project. The library is one of the buildings that implements the Green Architecture system (Green Construction). Green Architecture describes the economy, energy saving and environmentally friendly. The concept of environmentally friendly buildings has a contribution to halt the rate of global warming by improving the microclimate. One of the ways is by increasing the green plants and gardens that are needed to regulate the balance of the surrounding environment. The roof of the building is developed into a roof garden that has high ecological value (temperature drops, pollution decreases and green space increases). The selection of environmental materials is divided into two types, namely 1. the technology side, by avoiding the presence of toxins / poisons without contradicting nature, 2. the use side, the selection of materials that are environmentally friendly and energy efficient.

The library has a neat layout of books based on book categories with page numbering AA00, AA01, AA02 ... AA99, AB01, AB02, ... and so on. If pages BA13 to BG04 are missing, how many books are missing?

5. Alternative Solution

**Problem 1.**
In order to solve problem 1, the students start with the volume of the glass, which is 440 ml, and the water discharge 15 ml / sec.

\[
\text{Water Discharge} = \frac{\text{Volume of Glass}}{\text{Time}} = \frac{n \times V}{4} \quad \text{sec}
\]

\[
\text{Water Discharge} = \frac{n \times V}{4} \quad \text{sec}
\]

\[
\text{Time} = \frac{35 \times 3}{4} (440)
\]

\[
\text{Time} = \frac{35 \times 3}{4} (440)
\]

\[
\text{Time} = 12 \frac{5}{6} \text{ minutes}
\]
Time = 12 minutes 50 seconds

Problem 2.
To solve this problem, the students need to interpret the statement “it can move more quickly and economically”. Based on this fact, we can see the following impact number 5 is incorrect since extending the front of the train will not reduce air resistance. Thus, the correct explanation is 1, 2, 3 and 4.

Problem 3.
In order to answer this problem, the students can straightly jump to the main statement “The library has a neat layout of books based on book categories with page numbering AA00, AA01, AA02 ... AA99, AB01, AB02, ... and so on” and “BA13 to BG04 are missing”. Based on these facts, we can determine the missing books, such as:

- BA13 – BA99 = 87 books
- BB01 – BB99 = 99 books
- BC01 – BC99 = 99 books
- BD01 – BD99 = 99 books
- BE01 – BE99 = 99 books
- BF01 – BF99 = 99 books
- BG01 – BG04 = 4 books

Thus, there are 586 missing books in that library.

6. Students Reaction

Problem 1

The first problem was designed in order to acquire information about students’ understanding about the application of mathematics in science circumstances. About 25% of the total students who followed the pretest could answer the problems with insufficient descriptions; the rest of them just gave a short explanation towards the problem. In this case, an example of students’ written work can be seen in Figure 1 below.

Figure 1. Students’ strategy to Problem 1

In Figure 1, we can obviously see the student’s struggle to deal with problem 1. Although the answer is incorrect; however, we can see the student’s strategies to determine the answer. Basically, the student has already recognize the problem situation, but he/she probably has a doubt to find the
Volume of water after mixing with sugar. This situation may lead the students to a conclusion that it takes 12 minutes and 15 seconds to fill the whole glasses.

**Problem 2.**

The second problem was made to ask the students about the relation among Science, Technology, Engineering and Mathematics. In this problem, the students were asked to determine which train and railway construction would probably fit with the “more quickly and economically” conditions. The first condition that the students have to consider is the train must run fast. The second condition is the construction material should be economic.

Based on the table of “Part” and “Physical Reason”, we can see that the first choice meets the demand of the problem situation. Although students have no sufficient knowledge about physical material, however they can use their Higher Order Thinking Skills to find the relations. In this case, if the bottom rail replaced with superconducting magnets then there is a possibility that the situation makes the train’s body floats above the railway. Furthermore, if the it floats above the railway then there must be no friction so the train can run fast. The second condition also fits with the government requirement. In this case, changing the front of the train to resemble a dolphin head is meant to break the flow of air against the train. This part was designed to reduce the air resistance so it can increase the train speed. The third and fourth conditions are also correct for the government’s demands.

The last condition is not suitable with the demand since the changing part of the train does not impact to its physical reaction. In this case, if we extend the front part, it can possible reduce the train’s speed or this situation can make the train run slower and the students can not choose the last choice. Thus, the correct answers are no. 1, 2, 3, and 4. An example of students’ written work is illustrated in Figure 2 below.

**Figure 2. Students’ strategy to Problem 2**

Based on Figure 2, we can see that that the students attempt to solve the problem with picture manipulation. In the figure, the student drew three squares to represent the train and one rectangular square to illustrate the front of the train. This student also make the flow of the air that against the train. In this case, we could see that the students’ reason are sophisticated that he/she could use picture manipulation to describe the problem situation. He/she finally derived a conclusion that it is not possible to extend the front face since it can add the air in the front which can resist the train.

**Problem 3.**

The third problem was designed to acquire the information about students’ understanding about the relations among Science, Technology, Engineering and Mathematics in a context-based situation. In
order to deal with this problem, the students need to consider the order of the books in the library. In this case, only a few of them could give correct answer of this problem. Most of them misinterpret or even derived incorrect conclusion.

Based on the analysis of students’ written work, most of them attempted to solve this problem with word description and related to mathematical procedures. In this case, we depict an example of student’s explanation in Figure 3 below.

\[
\begin{align*}
15/ BA13 - BG04 \\
BA & \text{ ada 100} \\
A - G & \text{ barang 6} \\
BA13 - BB00 & \text{ ada 96 buku} \\
BB00 - BG00 & \text{ ada 100 x 6 = 600 buku} \\
BG00 - BG04 & \text{ ada 5 buku} \\
= 691 & \text{ buku}
\end{align*}
\]

**Figure 3.** Students’ strategy to Problem 3

Based Figure 3, we can see the students’ struggle in order to determine the solution of the third problem. Although the student yields incorrect solution, we can the students’ interpretation towards this problem. In this case, the student begin his/her strategy from the book order BA13 – BG 04. This student did not recognize that there are 99 books from BB01 to BB99. The student wrote there are 100 books from BB00 to BG00. This situation yields a mistake in determining the number of missing books which is the answer to the problem situation.

7. Conclusion

We are convinced that it takes time to develop students’ mathematical thinking, Higher Education. In answering the crucial question of this particular study, we used the analysis of the data collection, such as students’ written work and interview. One possible way to get the students’ reasoning on how they solve logical problems is by the commencement of a context-based STEM Problems. Commencing a context-based STEM Problems contextual problem can be meaningful if there is a good problem in it. A good context is a real-world context that entails meaningful and interesting problem which can possibly stimulate the students to think. Moreover, a good context can be designed through an open problem that cannot be answered by a standard algorithm and therefore encourages the students to apply their own explanations. Some examples can be obviously seen through the above students’ written work. For example, some students come up with drawing pictures. One possible reason is that the students use the pictures to represent the problem situation, in order to solve the first problem. Other students come up with their argumentations.

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