How to design open-ended questions? : Literature review

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Abstract: There are two types of questions that teachers can use in the learning process, that is closed-ended and open-ended questions, but only open-ended questions that can stimulate the students to develop their higher-order thinking skills. Although this type of question has an important function for students, it turns out the questions contained in the textbook are still in the form of closed-ended questions and to design open-ended questions takes a lot of time and effort. Therefore, a literature study is needed to find simple strategies that can be used to design open-ended questions. Based on the findings, there are 5 strategies that can be used to design open-ended question, namely modifying closed-ended questions, working backward, design the questions to determine “who is correct?”, using the problem-posing principle and design the questions to determine “what’s wrong with this?”. The results of this literature review also found that open-ended questions can also be used to identify students’ conceptual understanding, reasoning and misconception.

1. Introduction
In the daily life, we can’t be separated from the problems that need to be solved, such as choosing a breakfast menu, till the complex problem such as work problems. This problem requires people to have skills that can help them to solve the various problem they met. However, correspondence with the development of an increasingly sophisticated era, competition in the 21st century is getting tougher. In the 21st century, people need to be able to produce something new constantly, better than previously, can improve all conditions and have different abilities from the others in order to have a better job and life [1]. So people not only must have enough abilities to deal with the daily problems but also must have the ability to help them compete with others.

One of the 21st century’s abilities/skill should be had by humans is creativity [1]. Students as future citizens, not only need to acquire knowledge/cognitive skill at the school but also need to develop a higher level thinking skills that are useful for solving the real varied problems and help them in their daily life. It means that creativity needs students obtained at school.

The creative students will be able to understand and present the problem, find the solving pattern, make a generalization, take in analogy and relationship, look back the previous problem from different point of view, find the solution and evaluate it [2]. They will be more successful rather than the others in solving the problems in their daily lives and also be ready for facing the challenges of the times. Due to the importance of students’ creativity, the students should get the skill through the school’s lessons.
In other words, it becomes the crucial task for the teachers to develop students’ creativities through the teaching and learning activities [3].

One of the subject matter that taught in the school is mathematics. Mathematics is a science which has strong correlations with daily life. Therefore, in a mathematics learning, the students will be trained a skill that is useful in their daily lives, one of them is creative thinking skill [4]. Creative thinking skill is one of the abilities needed in mathematics, even students have a fairly high perception or 34% of the need for creativity in mathematics [5]. This ability will help the student to learn mathematics and develop their mathematical abilities. Because of that, this skill becomes a main component in mathematics learning [6]. The teacher needs to stimulate their students to think creatively in the learning process [7]. The strategy that can be used is by asking questions that are effective against development creative thinking skill.

Questions have an important role in the learning process, because it can be a tool for the teacher to interacting with their students, identifying students’ understanding, controlling the classroom environment, increase communication between the students and teacher and creating an atmosphere of class discussion, as well as guiding students to build knowledge and develop mathematical thinking skills [8, 9, 10, 11]. The questions used in learning are generally divided into open-ended questions and closed-ended questions.

Open-ended questions are questions that have more than one correct answer and accomplishment strategy. Whereas closed-ended questions are questions that only have one correct answer. Due to having one right answer, this question limits students to explore their thinking skills, but in the open-ended question, students are not limited to exploring their individual thinking abilities to answer the questions. This statement in line with Shriki which states that when students have the freedom to apply ideas and find diverse strategies, they can explain their thinking in finding varied answers, students will be able to develop their creative thinking skills [12].

Students' creative thinking skills can be improved by open-ended questions [12, 13, 14]. This type of question has three principles of openness, namely process is open (has more than one correct settlement strategy), end product open (has more than one solution/correct answer) and ways to develop open (can be developed into new problems by changing the initial conditions) [15]. The existence of these principles makes open-ended questions provide opportunities for students to explore them both in terms of answers, resolution strategies and further development.

However, students will not be able to solve open-ended questions if they are not able to think fluency, flexibility and originality to solve the problem. Fluency is the ability to give more than one correct answers. Flexibility is the ability to provide a correct new completion strategy, while Originality is the ability to provide unique or rarely solutions. These abilities are an indicator of creative thinking abilities [16]. Therefore open-ended questions can be effective to provide students with creative thinking skills.

Furthermore, open-ended questions also can be used to develop students' communication skills, because these type of questions can stimulate students to become more active in expressing their opinions, have more efficacy to use knowledge and skills and have rich experience in problem-solving processes [17]. Thus, open-ended questions are not only able to develop students' creative thinking skills but also makes the learning process become more active because more students participate.

However, using open-ended questions in the learning process is not easy. Because the majority of textbooks owned by students and teachers are still filled with standard problems or close-ended questions and make open-ended questions takes a lot of time and effort [18]. This fact makes the teacher still use the questions contained in the textbook or close-ended questions (questions that only have one correct answer, the others answer will be wrong). Whereas this type of questions has not been able to improve students’ creative thinking skill.

Even though it has been known that effective questions in learning are open-ended questions, but mathematics teachers are not too capable in asking good questions. Mathematics teacher asked 12-20 questions in their lesson, but half of them were related to schedules, attendance, clarification of various technical problems, close-ended questions and questions that only needed answers “right /wrong ” [10,
That questions do not require high-level thinking skills to answer them, so the questions given by the teacher doesn’t support for the development of students’ higher thinking skill.

Based on these explanations, the purpose of this article is for discussing strategies that can be done to design open-ended questions and to identify other objectives of the open-ended questions in mathematics learning.

2. Methods
This literature review has been undertaken through finding as much as possible the quantitative and qualitative empirical studies published in several leading journal international regarding open-ended questions. Paper traced using the publisher website such as ERIC database searches, JSTOR and manual searches by tracking citations from one study to another. The keywords used to traced the paper are “open-ended”, “questions” and “mathematics creativity”. Paper was analyzed for the period between 2000 and 2018, related to mathematics education in school. Based on this search procedure, there are 11 articles that will be used to answer the research objectives.

3. Result and Discussion
Based on the literature review, there are several strategies that can be used to design open-ended questions, that is

3.1 Modifying Close-Ended Questions
Close-ended questions are questions that have several known information/variable and only have one correct answer that can be obtained as a result of the relationship between these variables [21]. Furthermore, the answers of these questions are clear and resolved with certain rules/formulas. Close-ended questions contrast to open-ended questions because this type of questions does not provide opportunities for students to apply their own strategies to find different and new answers [13]. Therefore the close-ended questions are considered unable to develop students' mathematical thinking skills.

Making open-ended questions aren’t an easy task, because it is necessary to design questions that satisfy the principles of openness open-ended questions. But there is a simple strategy that can be used to design open-ended questions namely modifying close-ended questions become open-ended questions [22]. Even we can use the questions contained in the textbook to be modified into open-ended questions [23].

The steps of modifying closed-ended questions are as follows [22, 23, 24].

| Subject          | Identify Learning Topic | Making Close-Ended Questions | Modifying Close-Ended Questions to Open-Ended Questions |
|------------------|-------------------------|------------------------------|--------------------------------------------------------|
| **Geometry**     | Area of the plane       | Determine the area of the triangle that has a base of 8 cm and a height of 24 cm. | Given a triangle with an area of 96 cm², draw three examples of quadrilateral that has an area equal to that triangle. |
| **Numbers and Operations** | Addition | 337 + 456 = ... | On a trip home by train, I was calculating the distance. Suddenly I spilled drinks on my answer paper. My paper looks like the following
\[
3 \quad ? \quad 7
\]
\[
+ \quad ? \quad 6
\]
\[
7 \quad 9 \quad ?
\]
What number might be lost. |
Based on Table 1, it can be seen that a special way to modify close-ended questions into open-ended questions is modifying the information asked in close-ended questions become known information in open-ended questions. The results of the modification of the closed-ended question must give the students the opportunity to determine their own resolution strategies that are considered most appropriate.

The types of open-ended questions obtained through this strategy require students to think about a variety of possible answers that satisfied the known conditions in the questions. So, in order to be able to think about the possibility of the answer, students need to have a high understanding of the concept. Based on this, it can be concluded that open-ended question can be used to identify understanding concept [27].

3.2 Working Backward

In designing the question we generally work more forward, starting with compiling questions and then thinking about the answers. However, open-ended questions can also be made by working backward, as follows [24, 26].

Table 2. Design open-ended questions with working backward.

| Subject               | Identification of Learning Topic | Steps                                                      |
|-----------------------|---------------------------------|------------------------------------------------------------|
| Geometry              | Area of the plane               | Make questions involving the written answers              |
|                       | 8 cm²                           | Sketch as many different shapes as you can that have an area of 8 cm². |
| Numbers and Operations| Fraction                        | If two numbers are multiplied, the result is $5\frac{1}{2}$. What are the two possible numbers? |

3.3 Making questions to determine “Who is correct?”

One of the open-ended questions’ important points is these questions provide an opportunity for students to communicate what is in their minds or explain their reasoning process so that they can find the desired answer. One form of a question that can be used is a question to determine “who is correct?”, but this type of question must be accompanied by the question to explore students’ further explanation such as the “why” or ”how” questions [10, 27]. Examples are as follows:
Table 3. Examples questions to determine “Who is correct?”.

| Questions                                                                 | Possibility Students’ Answers                             |
|---------------------------------------------------------------------------|-----------------------------------------------------------|
| Fred thinks that 57 and 67 are prime numbers. But Dick said he was wrong. | Some students will answer that Fred is correct because the two numbers end with 7 which is a prime number. While some other students will answer that Dick is the correct one because 57 has other factors besides the number itself and the number 1 so 57 is not a prime number, while 67 is a prime number because it only has the number factor itself and 1. |

Based on Table 3, it can be seen that this question will produce two types of answer, which is agreed and disagree with the conditions given in open-ended questions [27]. If it is not accompanied by “why” or “how” question, the open-ended questions can only be true or false questions and student's answer can be only a lucky guess or imitate the other student answer. True or false questions are low-level questions, then in order to become high-level questions, this type of question must be accompanied by questions that require students to defend their answer and give an explanation about their reasoning process [27].

Furthermore, in Table 3 it can be seen that the open-ended question was made by this strategy requires students to communicate their reasoning process of the answer so that it will help them identify what they have understood and what can be used to answer the question and develop their thinking skills. This is because the questions that require an explanation from the student (not limited to “right” or “wrong” answer) will help them to communicate their understanding and improve their mathematical thinking skills [26]. Based on these findings, it can be concluded that open-ended questions can be used to identify students' reasoning, communicate their opinion/understanding, and improve students’ mathematical thinking skill.

Besides “why” and “how”, the type of questions can be used to stimulate students to communicate their understanding that is giving a response to students' answers by using the words "so ..", "then ...", and "therefore ..." [28]. These words can guide students to think more deeply about related concepts.

However, we need to be careful with this type of question, because whereas the question fits this form does not necessarily mean that the question is open-ended or high-level questions [27].

Example:

Jammie solved equation \( x + 5 = 10 \) and got \( x = 5 \). While Daniel solved equation \( x + 5 = 10 \) and got \( x = 15 \). Who is correct and why?

This type of the question is similar from asking the question “solve \( x + 5 = 10 \) for \( x \)”. This question is low-level questions because does not involve strong conceptual underpinnings of the equation solving [27].

3.4. Using problem posing principle

Problem posing is a term used to generalize of new problems or to reformulate a problem given [16]. One of the activities to create a new question in problem posing is the post-solution posing. In these activities, we will modify the purpose or condition of the problem that has been solved to generate new questions [29]. The situation or condition is modified using what-if-not strategies [12]. This strategy can stimulate students to generate new possible solution [13]. So that student not only receive the basic concept from the teacher or memorize a formula, but also understand the concept more deeply in the other representations.

For example:

Solutions : The area of a rectangular garden with 20 m x 12 m is 240 m².

New question : What if the width is not 20 m but it is 30 m, what happens and how is about its area.
3.5. Making questions to determine “What’s wrong with this?”

In this strategy, the open-ended question was made by presenting the erroneous example solution and then asked students to identify the error. There are two types of error that we can use to design open-ended questions, which is procedural error and conceptual error [30]. Procedural errors related to the errors in calculating the solution, while conceptual errors related to the errors in applying mathematical concepts to determine the answer.

This type of questions will provide opportunities for students to give different answers according to their thinking skill and conceptual understanding. These type of questions is an open-ended question because it has more than one answer [27]. When we ask this type of questions, students will be stimulated to use their higher thinking skill to identify the error and explain why that happens, so these type questions will stimulate the student to give a varied answer.

Daniela claims that the area of this following triangle is 54 cm$^2$

Based on Figure 1, the first possibility of student answer is Daniela’ solution is incorrect because she had a miscalculation. The correct multiplication result of $\frac{1}{2} \times 15 \, \text{cm} \times 6 \, \text{cm}$ is 45 cm$^2$. While the other student will answer that Daniela’ solution is incorrect because she misinterpreted the base and height of the triangle, its should is 10 cm and 6 cm, and then the area of the triangle is 30 cm$^2$. Even there is a possibility that the other student can also answer that the area of triangle can’t be determined because the height of the triangle is unknown.

Based on Figure 1, this open-ended question requires students to identify the error part of a question solution and explain why or how they are an error. These type of open-ended questions can be used to identify misconceptions because students are required to think critically about a common misconception [27, 31]. There are two types of errors found in these open-ended questions, that is conceptual errors and procedural errors. If students are not able to give the correct answer and answer this question, this means that conceptual understanding that has been held by students is still incorrect or students experience misconception. Students must be able to identify conceptual and procedural errors from the question given and provide the correct answers. Based on these findings, it can be concluded that open-ended questions can be used to identify students misconception.

4. Conclusion

There are several strategies that can be used to design Open-Ended questions as follows: (1) modifying closed-ended questions, it is done by changing the information asked in closed-ended questions into known information in open-ended questions: (2) working backwards, it is done by thinking about the answers to open-ended questions, then thinking about the strategy to get the answers and writing them in the form of questions; (3) Making a questions to determine “who is correct?”, this question asks student’s opinion and their own reasoning processes; (4) using the problem-posing principle, it is done by modifying the questions that have been answered using the "what-if-not?" strategy; and (5) making questions to determine “what’s wrong with this?”, it is done by presenting an erroneous example solution.
and then ask the student to identify the error part and explain why they error then the student must provide the correct answer.

Based on the result and discussion, there are other objectives of using open-ended questions in mathematics learning besides improving the student’s creative thinking skill. Open-ended questions can be used to identify students’ understanding of concepts, reasoning, misconceptions and to encourage the student to communicate their opinion/understanding.

Open-Ended questions are important for students’ learning and mathematical thinking skill. Hence, we should habituate them with these type of questions. This article just is limited to literature study, it is hoped, there will be further researches about the implementation of strategies to design open-ended questions and the effectiveness of open-ended questions toward students' ability to understand concepts, reasoning, and misconceptions.

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