PROBING STUDENT EXPLANATION

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Previous studies have produced several typologies of teacher questions. Often probing questions that require students to explain are included into the types of questions. However, studies that have created subtypes for probing questions are rare. The aim of this study is to elaborate on different ways of asking students to explain in mathematics. Altogether, 29 pre-service teachers' lessons were videotaped. The videotapes were coded for teachers' probing questions. After this, I used the grounded theory approach to create categories for types of probing questions: probing solution method, probing reasoning, probing argument, probing reason for something, probing meaning, probing extension, and unfocused probing questions. The types of probing questions are discussed in the paper.

INTRODUCTION

Several studies highlight the importance of asking students to explain. There is evidence that student explanation has a positive effect on learning and strengthens students' understanding (Rittle-Johnson, 2006; Wong et al., 2002). Explanations also make students' thinking visible and allow the teacher to proceed accordingly (Ruiz-Primo, 2011). Furthermore, asking students to explain is important in supporting dialogic interaction (McNeill & Pimentel, 2009) and in creating learning possibilities for other students too. According to Kazemi and Stipek (2001), teachers' ways of asking questions affect students' explanation behaviour. Hunter (2008) reported that students also learned to ask explanations from each others.

Traditionally good teachers are considered as good explainers. However, nowadays more emphasis is placed on getting the students to explain. In particular, inquiry-based mathematics teaching highlights the importance of student explanation (e.g., Kazemi & Stipek, 2001). In this study, inquiry-based mathematics teaching means that students work alone or in small groups to solve non-standard mathematical problems designed to potentially bring forth mathematical ideas related to the topic at hand while the teacher supports students' reasoning and orchestrates classroom discussion. In line with Stein, Engle, Smith, and Hughes (2008), inquiry-based mathematics teaching consists of launch, explore, and discuss and summarize phases. The teacher introduces the problems in the launch phase. Then, students work in small groups during the explore phase. Finally, students' solutions are discussed in the discus and summarize phase. The main idea of inquiry-based mathematics teaching is that a teacher has a crucial role in activating students to reason more and more mathematically and to build mathematical explanations for their findings (Hähkiöniemi & Leppäaho, 2012).

Questions that ask students to explain are usually considered higher order questions. For example, Kawanaka and Stigler (1999) consider higher order questions requesting

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an explanation or description of a mathematical object, solution method, or a reason why something is true or not true. They found that 9.6 % of German, 22 % of Japanese, and 1 % of U.S. eight-grade teachers' questions were higher order questions. The rest of the questions asked for a yes or no answer or to state a fact. Also other studies have found that the proportion of questions that ask for explanation is relatively small (e.g., Myhill & Dunkin, 2005; Sahin & Kulm, 2008).

Sahin and Kulm (2008) consider three types of mathematics teachers' questions: factual, guiding, and probing questions. Factual questions request a known fact, guiding questions give hints or scaffold solution, and probing questions ask for elaboration, explanation or justification (Sahin & Kulm, 2008). Sahin and Kulm used the following three criteria for identifying probing questions: (1) ask students to explain or elaborate their thinking, (2) ask students to use prior knowledge and apply it to a current problem or idea, (3) ask students to justify or prove their ideas. They found that the two sixth-grade teachers' use of probing questions varied from 17 % to 42 %.

Despite several classification schemes of teacher questions, studies that suggest different subcategories for questions that ask for explanation are rare. One such study is Kawanaka and Stigler's (1999) study. According to them, higher order questions may request (1) analysis, synthesis, conjecture or evaluation, (2) how to proceed in solving a problem, (3) methods that were used to solve the problem, (4) reasons why something is true, why something works or why something is done, or (5) other information. Kawanaka and Stigler (1999) found that the teachers in the three countries asked different kinds of higher order questions.

The aim of this study is to further elaborate on different ways of asking students to explain in mathematics. Particularly, I construct subcategories for different types of probing questions that request explanation. The subcategories help us to understand the complexity of explanation asking. The following research question guided the data analysis: In what ways do teachers ask probing questions that invite students to explain?

METHODS

Data collection

The data of this study is a part of a larger study on pre-service teachers' implementation of inquiry-based mathematics teaching. 29 pre-service teachers participated to an inquiry-based mathematics teaching unit. The unit included nine 90 minutes group work sessions about the ideas of inquiry-based mathematics teaching. For example, the pre-service teachers practiced how to guide students in hypothetical teaching situations (see, Hähkiöniemi & Leppäaho, 2012). Then, each pre-service teacher implemented one inquiry mathematics lesson in grades 7–12. All the lessons were structured in the launch, explore, and discus and summarize phases. Students used GeoGebra to solve problems in 17 lessons.

The lessons were videotaped and audio recorded with a wireless microphone attached to the teacher. The video camera followed the teacher as he or she moved around the

classroom. When the teacher discussed with a student pair, the camera was positioned so that students' notebooks or computer screens could be seen. Students written notes were collected after each lesson. Additional data, which is not used in this paper, includes video recorded debriefing sessions, audio recorded stimulated recall interviews of the teachers, and video recorded work of focus students with additional camera.

Data analysis

Data was analysed using Atlas.ti video analysis software. All the teachers' subject related questions were coded to probing, guiding, and factual questions. The definitions for these codes were constructed on the basis of Sahin and Kulm's (2008) definitions. All teacher utterances which requested students to explain or examine their thinking, solution method or a mathematical idea were coded as probing questions. A teacher utterance was considered as a question if it invited the students to give an oral response. For example, utterances such as "explain" were considered as questions even though grammatically they are not questions. On the other hand, grammatical questions were not coded as questions if the teacher did not give the students a possibility to answer the question.

After this, all the probing questions were further analysed. The grounded theory (Glaser & Strauss, 1967) approach was applied. First I viewed to the probing questions several times to become familiar with them. Then, I clustered the probing questions into categories. I constructed the categories by interpreting what the teacher asks students to explain. I used the method of constant comparison (Glaser & Strauss, 1967) as I compared each coded question to the other questions coded to the same category. In addition, I compared how each question would fit to the other categories. After creating the categories, I examined the properties of the categories by viewing repeatedly the questions of a certain category. I also compared the categories to each other and explored relations between them. Through this process I organised the categories into main categories (see Table 1). Due to space limitations, only the main categories are discussed in this paper.

RESULTS

Altogether, the pre-service teachers asked 345 probing questions that is 25 % of all the subject related questions. The categories of probing questions are presented in Table 1. Below, I elaborate on the different types of probing questions that the pre-service teachers asked.

Type of a probing question	Frequency	Percentages
Probing solution method	96	28 %
Probing reasoning	70	20 %
Probing argument	37	11 %
Probing reason for something	61	18 %
Probing meaning	46	13 %
Probing extension	14	4 %
Unfocused probing questions	21	6 %

Table 1: The types of probing questions asked by the pre-service teachers' (n = 29).

Probing solution method

In these kinds of probing questions, a teacher asked students to explain how they solved a problem or what they did. For example, in an 8th grade lesson about percentages, a pair of students was solving how much juice can be made of 1.5 litres of concentrate when 30 % of the juice has to be concentrate. The students had solved the problem as shown in Figure 1, when the teacher came to talk with the students:

Teacher: Explain a little what you have done here [invites oral response].

Student: We took first 10 % which is this 0.5. Then we multiplied it by 7 to get 70 %. Then we added the 30 % to 70 %.

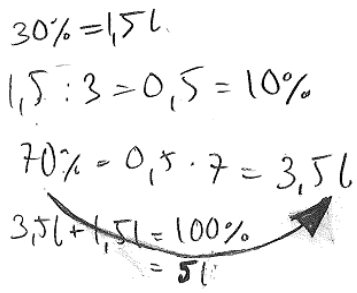

Fig. 1. Students' solution of how much juice can be made of 1.5 litres of concentrate when 30 % of the juice has to be concentrate.

The teacher's utterance was a question in a sense that it invited an oral response from the students. The question explicitly asked the students to explain what they did encouraging the students to explain how they solved the problem.

This category includes also questions that ask how students reached a solution without clearly expressing whether students should explain what they did or how they reasoned. For example, the teacher discussed with another student pair about the same task as above:

Teacher: Where did you get that kind of an equation [$x \cdot 0.30 = 1.5$]?

Student: Well, you need 30 % concentrate. So. This is 30 %. So, when x is multiplied by it we get 30 % of x which is 1.5.

In this case, the student actually responded by explaining the reasoning behind the equation.

Probing reasoning

This category includes questions in which a teacher asked students to explain what they are thinking, how they reasoned something, how something could be reasoned, how they invented something, or what kind of problem they have in their thinking. The difference to the previous category is that a teacher explicitly asked to explain reasoning or thinking. For example, in a 10th grade lesson about the contingence angle of two tangents to a circle, a student claimed that the sum of the central angle and the angle of contingence is 180° (see Fig. 2). Then, the teacher asked her to explain how she reasoned it:

Teacher: From which did you conclude it?

Student: Because the two other angles are 90, it becomes 180 [sum of the angles C and D], and because this is quadrangle, it is 360 [sum of the angles A, B, C, and D].

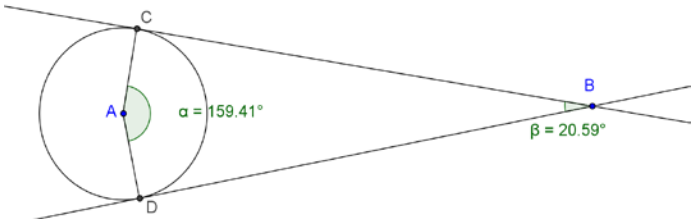

Fig. 2. GeoGebra applet for investigating the sum of the contingence angle and central angle.

In this case, the student responded by explaining her reasoning. However, sometimes students explained what they did even though the teacher asked about reasoning.

Probing argument

In these kinds of probing questions, a teacher asked students to give arguments by requesting justification, how students know something, or whether something really is as students claim. For example, in an 11th grade lesson about logarithm included the following whole class discussion about $\log_2 16$:

Student: We got 4.

Teacher: Yeah. What would be the argument?

Student: Because 2 to 4 equals 16. Isn't it? 4 to 2. I don't know.

In this case, the teacher asked the student to justify his answer but the student was not sure about the justification.

Probing reason for something

When probing reason for something the teachers asked students to explain reason why something is as it is or why the students did something. For example, in a 9th grade lesson about divisibility rules, a student claimed that a number is divisible by two if the last digit is even. Then, the following discussion occurred:

Teacher: What is the reason, could you..?

Student: Because they are divisible by two. […]

Teacher: Why is it enough to look at the last digit?

Student: Because if the last one would by odd, then the number could not be divisible by two. […]

Teacher: What is the reason that you can divide the whole number by two? I can see that you can divide four [by two].

Student: They are round thousands, round hundreds, round tens, to which only the digit in the end is added to. So it is the one digit which matters instead of the whole number. […]They are complete thousands, hundreds, and tens, which all are divisible by two, and therefore, the whole number is divisible by two if the last one is not odd.

In this episode, the teacher repeatedly asked the student to explain the reason for the divisibility rule noticed by the student. At first, the student seemed not to understand what kind of reason is asked for, but finally, when the teacher kept on asking, the student formulated mathematical explanation for the divisibility rule.

Probing meaning

This category includes questions in which a teacher asked students to explain the meaning of something. For example, in a 7th grade lesson about the concept of variable, the teacher asked about the formula that a student pair had constructed to describe a certain phenomenon:

Teacher: Tell about this. What does this mean [the students' formula $h \cdot 5 + 2$]?

Student: Every hour costs 5 Euros plus the 2 Euros entrance fee.

Often, the pre-service teachers did not explicitly ask for meaning as above but, for example, "what happens here?" In the latter case, students are still expected to explain what they mean by something. This category includes also questions that encourage students to explain more, and thus, clarify what they mean. For example, a teacher encouraged a student to explain the meaning of a figure by asking "What do you have in the figure?"

Probing extension

In these kinds of probing questions, a teacher asked students to explain how their solution method would work in a slightly different situation or how the problem could be solved differently. These questions invite to explain how a solution could be extended to a new direction. For example, a teacher asked this kind of question in an 11th grade lesson about continuity when a group of students said that a certain piecewise function is continuous because the graphs given by the calculator overlap:

Teacher: If you calculated it, what would happen? […] How could you calculate whether the graphs overlap without drawing the graphs?

Student: Is it possible to calculate the intersection points? If you substitute $x = 1$, it will not be possible.

In the above episode, the teacher's questions steered the students to consider using the equation of the function in addition to the graph of the function. The question also invited students to explain how they could do this. Thus, the question was a probing question which asked students to extend their solution to a new direction. The difference to guiding question is that students are invited to examine their solution in relation to the potential extension suggested by the teacher. In contrast, guiding questions help students to solve the problem in first place.

Unfocused probing questions

Unfocused probing questions invite students to explain but it is not expressed what should be explained. For example, this category includes the following questions: "Would you like to say something [about the solution of a problem]?" and "Do you have an idea?"

DISCUSSION

The results of this study show that there are several different types of probing questions. Although all probing questions request explanation, different things are asked to be explained. Previous studies have proposed several questioning typologies which often include questions that ask for explanation (e.g., Kawanaka & Stigler, 1999; Myhill & Dunkin, 2005; Sahin & Kulm, 2008). This study created subtypes for probing questions: probing solution method, probing reasoning, probing argument, probing reason for something, probing meaning, probing new idea, and unfocused probing questions.

Some of the categories of probing questions resemble those of previous studies. The category of probing solution method is similar to Kawanaka and Stigler's (1999) question types asking for how to proceed in solving a problem and methods that were used to solve a problem. The other question types of Kawanaka and Stigler (1999) do not have such a clear correspondence. For example, reasons are asked in the categories of probing reasoning, probing argument, and probing reason for something. When compared to Sahin and Kulm's (2008) three criteria of probing questions, the justification criteria is similar to probing argument and the criteria of applying previous knowledge resembles slightly the category of probing extension.

A relatively big proportion of the pre-service teachers' questions were probing questions when compared to previous studies (Kawanaka & Stigler, 1999; Myhill & Dunkin, 2005; Sahin & Kulm, 2008). Thus, it seems that pre-service teachers are prepared to ask probing questions. However, a large proportion (28 %) of the probing questions requested students to explain how they solved a problem. Kawanaka and Stigler (1999) reported even larger proportion of this kind of questions. Thus, teachers need to be aware of what they ask students to explain and ensure that students engage also in explaining their reasoning (cf. Kazemi & Stipek, 2001). However, students do not always explain their reasoning even though asked for. Thus, teacher needs to keep on asking reasoning with slightly different words as illustrated in the results (probing reason for something). In future research, it would be interesting to study how the types of probing questions are related to types of students' explanations.

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