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Guiding student thinking through teacher questioning when learning with dynamic representations

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Abstract Dynamic representations (e.g. dynamic geometry software GeoGebra for mathematics learning and PhET simulations for science learning) offer excellent opportunities for students to conduct investigations and to formulate explanations for the visualized phenomena. In order for this to be effective, students need guidance, for example, for planning their investigations and reflecting on their actions. One way to support students is by prompting them by using questions that are adapted to the students' current situation. This chapter focuses on how pre-service teachers provide guidance for students through questioning and by both structuring and problematizing student learning. Data comes from science lessons taught by pre-service primary school teachers and mathematics lessons taught by pre-service subject teachers. The analysis focused on the different question types the pre-service teachers used as well as how their questioning was adapted to students' situation. The results show how the pre-service teachers used questions both to structure student thinking and to problematize their answers and reasoning. Questioning was not always adapted to the students' needs. We propose that adapting teacher questioning to student thinking requires balancing between structuring and problematizing and high-level of interpretation from the teacher. Teachers' skills for interpretation are still beyond the skills of software. Implications for teaching with dynamic representations are discussed.

Keywords: pre-service teachers; teacher guidance; inquiry-based learning; simulations; STEM education

Background and literature review

Simulations for science learning and dynamic geometry software for mathematics learning have opened up new possibilities for teaching and learning (de Jong, 2006; Cai, van Joolingen & Walker, 2019). As both of them offer a chance for students to interact with the representations and manipulate the different objects and their properties, these are often referred as dynamic representations (Ainsworth & Van Labeke, 2004) (opposed to static representations that cannot be manipulated).
Dynamic representations enable the students to experiment with variables and objects and thus discover different scientific and mathematical principles through an active learning process (de Jong & Lazonder, 2014). Unguided inquiry-based learning is criticized for being less effective and efficient than direct instruction for novice learners (Kirschner, Sweller & Clark, 2004). The processes involved in inquiry-based learning such as interpreting data and drawing conclusions are difficult for learners without high level of prior knowledge or experience (de Jong & van Joolingen, 1998). The students also tend to focus on completing tasks instead of deepening their knowledge (Krajcik, Blumenfeld, Marx, Bass & Fredericks, 1998). It is clear that guidance (i.e. assistance that aims to simplify, provide a view on, elicit, supplant, or prescribe the reasoning skills involved (Lazonder & Harmsen, 2016)) must be provided either through the software itself, learning material or by the teacher (Lehtinen & Viiri, 2017). Reiser (2004) proposes two mechanisms for supporting learning: *structuring* and *problematizing*. Structuring refers to reducing complexity and choice by providing additional structure to the task. This can happen through e.g. dividing complex tasks into smaller parts or focusing student effort into the parts of the task that are most productive for learning. Problematizing refers to e.g. eliciting explicit student reasoning by pointing out important distinctions or distinguishing surface-level thinking and disagreements within a group.
One factor that promotes guidance provided by a teacher instead of software or learning material is the teachers' superior possibilities to adapt their guidance to the students' needs (Lehtinen & Viiri, 2017; de Jong & Lazonder, 2014). The process of adapting guidance requires the teacher to notice and recognize student thinking (Sherin, Jacobs, Phillipp, 2011) and use this information coming from multiple sources including their talk, actions and even from their body language (Ruiz-Primo, 2011) to guide the students on-the-fly. Then this information needs to be interpreted and used to guide the students' actions and to help them achieve the learning goals. At the same time the teacher should balance between structuring student work and problematizing it based on their needs (Reiser, 2004).
Especially teacher questions can be used both to elicit and probe students' ideas and stimulate productive and higher-order thinking (Chin, 2007) and to provide guidance for the students (Sahin & Kulm, 2008). Sahin and Kulm (2008) distinguish between these two uses for questioning by describing different question types. *Probing questions* are questions that ask the students to explain or elaborate their

thinking, use prior knowledge and apply it to a current problem or idea or ask students to justify or prove their ideas. On the other hand, *guiding questions* ask for a specific answer, ask students to think about or recall a general heuristic or contain a sequence of factual questions to provide ideas or hints that guide toward understanding a concept or completing a procedure. As a third question type, Sahin and Kulm (2008) distinguish factual questions that ask for a specific fact or definition, an answer to an exercise or the next step in a procedure.

Lehtinen and Hähkiöniemi (2016) studied how pre-service teachers used spaces that a simulation created for explanation to probe for students' explanations through probing questions. Even though the explanations were prompted, they were not always used to adapt the following guidance. Hähkiöniemi (2015) found that pre-service mathematics teachers who asked series of guiding questions directed students towards finding an answer through a specific route whereas those who asked series of probing questions elicited learners' thinking and directed them towards forming explanations. These two ways of using questions have a connection with the two mechanisms of supporting learning proposed by Reiser (2004). Adapting guidance can be seen in one part as choosing between problematizing and structuring student learning.

The aims of this chapter are to analyze 1) the processes of structuring and problematizing student learning with dynamic representations and 2) how guidance provided by teacher questioning is adapted to the needs of the students. We examine these instructional practices via two cases from two different contexts where pre-service teachers (PSTs) guide a small group of students – one from upper secondary school mathematics and the other from primary school science. The research question is "How do pre-service teachers structure and problematize student learning with dynamic representations through adaptive questioning?"

Methods

We examined data from two sources in order to have richer set of data regarding different ages and different dynamic representations. The first data source is a project about GeoGebra-enriched (www.geogebra.org) inquiry-based mathematics teaching in Finnish lower and upper secondary schools. More details about this project is given in Hähkiöniemi (2017). The second data source is a project about using PhET simulations (http://phet.colorado.edu/en/simulations/) as a part of inquiry-based science teaching in Finnish primary schools. More details about this project is given in Lehtinen and Viiri (2017).

Data collection

Lessons in both projects were video-recorded. 29 lessons were videotaped for the mathematics education project and 8 for the science education project. One video camera recorded the teachers' actions and talk. The students' actions with the dynamic representation software and the discussions they were having with the PST were recorded either with a hand-held video camera (mathematics lessons) or through a screen capture program (science lessons).
The data analyzed in this chapter are discussions from two of the lessons (one from mathematics and one from science) where a PST guided a small group of students in their investigations. Both lessons contained an introduction, group work and whole class discussion.
The mathematics lesson chosen for analysis (episodes 1 and 3) was a 90-minute 10th grade lesson (short syllabus) about the contingence angle of two tangents to a circle. During group work, students worked in groups of two to four using a computer. They used a beforehand prepared applet (Fig. 1) to solve the following tasks:

- What is the size of the angle between the line and the segment *CA*? What is the size of the angle between the other line and the segment *DA*?
- How big can the central angle α be, if the location of the point *B* is changed?
- When are the angles α and β equal?
- Is there some kind of connection between the angles α and β?

The purpose of the task was to engage students in making observations, noticing patterns and generating conjectures through experimenting with dynamic geometry software and then explaining or justifying these through deductive reasoning. Thus, the task included aspects that are considered as important affordances of using dynamic geometry software in mathematics learning (e.g., Hähkiöniemi, Leppäaho & Francisco, 2013).

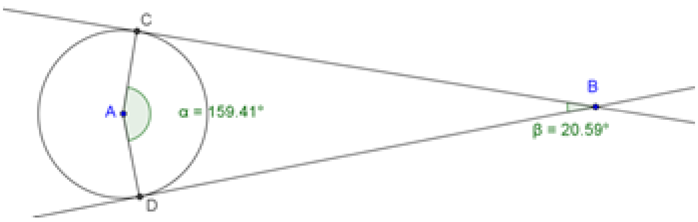

Fig. 1. GeoGebra applet in which one can drag points *A* and *B* (see https://ggbm.at/acMDDeae).

The science lesson chosen for analysis (episode 2) was a 3rd grade 45-minute lesson about the variables that affect the balance of a seesaw. During the group work, students worked in groups of three to five using a computer with a PST guiding them. The students used the "Balancing Act" PhET simulation to first explore balance through exploration with different weights and a seesaw. After this, the simulation provided the students with the following types of tasks:

- Where to place an object with a known mass to the seesaw (where another object with a known mass already is) in order to balance it?
- Which way will the seesaw turn? (Fig. 2)
- What is the mass of an object? (The students had to use an object with known mass and the seesaw to deduce the mass)

In principle, the tasks required the students to apply the moment arm rule that they could discover beforehand through exploration. As the students were 3rd graders, they were not able to formulate the rule in its entirety. Instead, they came up with qualitative or simpler formulas that still allowed them to solve some of the tasks.

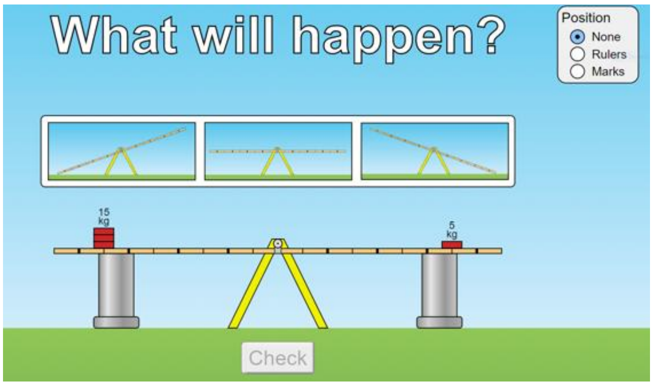

Fig. 2. An example task from the "Balancing Act" –simulation.

Data analysis

From the lesson transcripts, teacher questions were coded based on the categories by Sahin and Kulm (2008): probing, guiding and factual questions (see definitions in the previous section). Teacher utterances were considered questions if they invited the learners to produce an oral response. For the mathematics lessons the inter-rater agreement was 89% (sample of 150 questions) and Cohen's κ = .845 and for science lessons the inter-rater agreement (for a sample of 101 questions i.e. 12% of the questions) was 90% and Cohen's κ = .832. After coding the teachers' questions, the transcripts were divided into episodes that were marked by a change in topic, contrast in behavior or transition to the next type of conversation or activity (Jordan & Henderson, 1995). The episodes were then analyzed based on the features of structuring or problematizing student learning. In the end, three episodes (that came from two lessons) were chosen for further analysis for showcasing three different ways of structuring and problematizing student learning using adaptive teacher questioning.

Results

The results and analysis are reported episode by episode.

Episode 1: Adapting questioning to students' thinking by problematizing

A group of four students had wondered many of the given tasks when the PST came to discuss with them.

1 PST 1: Then, what is the connection between the angles α and β? (Factual)
2 Student: We did not even get the idea of the task.
3 PST 1: Oh well, it means that if they like depend on each other. Is it like…
4 Student A: They go like in the same proportion.
5 PST 1: Yeah, so if you know, for example, α, can you calculate β? (Guiding)
6 Student: Yeah. [Student mumbles something about a square and points to the screen.]
7 PST 1: Yeah, if it is a square, you can calculate that? Isn't it like that? Well, what if it is not a square? Can you still calculate it somehow? (Guiding)
8 Student: You can.
9 PST 1: How? (Guiding)
[Silence, 15 s. Students drag points and look at the screen.]
10 Student A: Yes you can. Yeah, now I got it.
11 PST 1: So.
12 Student A: Because these. Because these are 90 [points to C and D] and this is 360 in total [points to the quadrangle ADBC], then only calculate these and you will get it from that.
13 PST 1: Uh-hum. Right.
14 Student: Yay.
15 PST 1: But now, there is the question that how did you reason that this is 90 degrees. (Probing)
16 Student A: Well, because this is a circ-. Well okay.
17 Students: [inaudible]
18 PST 1: How did you reason that it is 90 degrees? (Probing)
19 Student: [Mumbles something about a quadrangle.]
20 Student: A quadrangle.
21 PST 1: It is not quite enough for it.
22 Student A: Yeah, it isn't.

In this episode, the PST noticed that the students do not understand the task through questioning (turn 1). This information was used to guide the students through structuring the task into a more closed one (turns 3 and 5). After the students had understood the task, the answer they provided is just for a special situation. The PST problematized this (turns 7 and 9) and the students were then able to provide a more general solution after manipulating the dynamic representation (turn 12). Building on their answer the PST probed the students for their reasoning (turns 15 and 18). When they were unable to provide this, the PST moved on. The question about the justification of the angle between the tangent and radius was a challenging question as several groups had difficulties in the justification. The PST turned to this issue during the closing whole class discussion.

Episode 2: Not adapting questioning to student thinking by structuring

The students were completing the tasks that the simulation provided for them. Previously, the tasks had asked them to place a certain weight to the seesaw in order to balance it. The current task asked whether the seesaw would tilt to the left, stay in balance or tilt to the right when there is a 5 kg weight on the left and a 15 kg weight of the right. The distance from the fulcrum was the same for both of the weights.

23 Student B: So now…
24 Student C: We'll have to move this one that way
25 Student B: Yeah we'll have to move this that way so
26 PST 2: That is right but in this one you don't have to move them but if the situation is like this that there is fifteen kilos in that place and this one is here so which one of these will happen (probing)
27 Student C: So in here happens like this that it first goes like this because this one like goes away and then in here it is in balance and in here it kind of goes away
28 PST 2: Mmm but if
29 Student A: I think it is that one. [Student A points to the correct answer]
30 PST 2: Which of these is more—which one is heavier? (guiding)
31 Student C: This one. [points to the 15-kg weight]
32 PST 2: This one—are these on the same line? (guiding)
33 Students B ja C: Yes.
34 PST 2: Yes, so if this one is heavier, then what will happen? (guiding)
35 Student C: It goes down.
36 Student B: It goes there, so that picture.
37 PST 2: Ok, try it and press "Check answer".
38 Student A: Yes, it was.

Again in this episode, at first the students did not understand the task (turns 24 and 25) and tried to manipulate the dynamic representation in a way that was not possible. Compared to the first episode, this time the PST simply verbally prompted the students (turn 26) when they had not understood the task in writing. After the students had understood the task, they were able to provide the right answer but without explaining why it would be the correct one (turn 29). The PST did not problematize this or prompt the students for reasoning for their answer. Instead, he/she structured the students' learning by implicitly providing them with a rule that they could use to solve similar tasks (turns 30, 32 and 34). Through a series of answers, the students were implicitly reasoning for their answer but this was not made explicit for the students, as the question chain did not start from the students' answer.

Episode 3: Adapting questioning to student thinking by both problematizing and structuring

A student had been mainly working alone although he had been assigned a pair. The student had thought about the tasks when the PST started to discuss with him.

39 PST 1: How about then this, how big can the central angle be if you drag *B*? (Factual)
40 Student: Well, it varies greatly. If you drag it here, to the far end [points to the corner of the window], then it would be 163.45. If it would be very close, like here, then it would be 9.33 [points close to the circle] and then here it would of course be 360 [moves a finger along the circle].
41 PST 1: How about, take, uh-hum. Let's move this. Now you can drag it more and more. [Teacher zooms out and drags the point B farther away from the circle.]
42 Student: Oh, you can do like that..
43 PST 1: Uh-hum. When would this be the biggest? You can drag this pretty far away. You can place it as far as you like. Nevertheless, what would the central angle bee when it is the biggest? (Guiding)
44 Student: Isn't it 360.
45 PST 1: Uh. This. So.
46 Student: Oh.
47 PST 1: Like the angle between these [shows the angle]. (Guiding)
48 Student: I would say that it is 180 here [makes a gesture of 180°].
49 PST 1: Can it be 180? (Guiding)
50 Student: [Silence, 4s.] Yes, I think that it can be.
51 PST 1: Uh. So this would be 180. How would these two lines go then [points to the tangent lines]? If some line would intersect them like that? (Guiding)
52 Student: Like parallel?
53 PST 1: Yeah. If they are parallel, then what would happen to this point here? If these two are parallel and this is the intersection point of them. (Guiding)
54 Student: Then it could not be there because these go like in parallel.
55 PST 1: Yeah, right. So it cannot newer be 180, can't it.
56 Student: So it cannot be 180.
57 PST 1: But what, yeah. It will, however, get very close to it, wont it.
58 Student: Yeah.

In this episode, the student's difficulty was initially not about understanding the task but about how to use the dynamic representation to investigate. The teacher noticed this from the student's incomplete answer (turn 40) and showed how to use the software (turns 41 and 43). After this, the student had difficulties in recognizing the correct angle to study (turn 44). The PST showed him/her the correct angle (turn 47). This information and correct manipulation of the representation enabled the student to answer the task (turn 48). The answer was almost correct. The PST noticed and problematized this. The student's answer was confirmed with a guiding question (turn 49). After this, the PST structured student reasoning through a series of guiding questions (turns 51 and 53) building on their original answer.

Discussion

The results of this study show how teacher questioning *can be* but *is not always* adapted to student thinking when using dynamic representations. The analyzed episodes differed in both the adaptation of teacher guidance and how the student learning was structured or problematized. In all of the episodes, the students misunderstood the assigned tasks in many ways. In the first episode, the students did not understand what kind of connection they were asked for. In the second episode, the students did not notice that the task differed from the previous one. In the third episode, the student did not understand how he/she was asked to use the dynamic representation to solve the task. To respond to these difficulties, in all of the episodes, the PSTs first interpreted the difficulty and then tailored questions to help the students to understand the task properly. The help was offered in the form of questions which rephrased the task to be more concrete (episode 1), rephrased the task to clarify how the use of dynamic representation differed from a previous task (episode 2) or first showing how to use the dynamic representation appropriately (episode 3). We interpret that in these instances the teachers adapted their questioning to the specific difficulty the students were confronting. This is similar to Hähkiöniemi et al.'s (2013) study, in which a teacher either narrowed or widened the starting situation of an open problem depending on the students' work so far. In addition, a crucial feature of adapting teacher questioning to students' difficulties in understanding a problem is to just help them to understand the problem but not unnecessarily reduce the cognitive demand as sometimes happens when challenging problems are implemented (Stein, Grover, & Henningsen, 1996).

After the students understood the tasks, there were still several issues that the PSTs needed to interpret and react to. In the first episode, students first proposed only a special case for a solution, and finally, when prosing a general solution, their justification needed reworking. In the second episode, the students gave only an answer without underlying reasoning. In the third episode, the student had another flaw in understanding the problem and, after understanding the problem, suggested a slightly incorrect answer. In the first and third episodes, the PST raised the issues that needed more consideration and prompted students to think about them either through probing or guiding questions. On the contrary, in the second episode the PST straight away asked a sequence of guiding questions that implicitly provided the students with a way to reason for their answer. Thus the PST was using questions to structure (Reiser, 2004) students' thinking whereas in the other episodes, the PSTs were using questions to problematize (Reiser, 2004) thinking. We propose that *adapting teacher questioning is balancing between structuring and problematizing and requires high level of interpretation*. In the first and third episodes, questioning is adapted as the problematic issues are problematized. However, in the second episode, questioning is not adapted because the PST is structuring students' thinking without basing it on students' own reasoning. The PST does not make an effort to interpret student thinking and whether structuring was needed. Of course, this does not imply that structuring means always that the questions are not adapted. For example, in the third episode, the PST adapted questioning by structuring the student's thinking because after problematizing the student was still adhering to an incorrect idea. The difference there was that the PST made an effort to interpret student thinking via first problematizing by questioning and thus the following structuring was based on the student's knowledge.

We have proposed here that adapting questions to students' current situation in a dynamic representation is an essential feature in guiding students' learning. Moreover, we have proposed that adapting questions happens through interpreting student thinking and then balancing between structuring and problematizing through questioning. This resonates with formative assessment discussions in which teachers probe for information about student learning and then use this information to promote learning (Nieminen et al., 2020; Ruiz-Primo, 2011). Both concepts emphasize teacher noticing (Sherin, Jacobs, Phillipp, 2011) where that teacher is continuously scanning the lesson to recognize important events. In adapting questions, student idea is recognized, then interpreted and an appropriate question is asked. Previous studies have suggested benefits of teachers basing their guidance on high level interpretation of student work (Sherin, Jacobs, & Philipp, 2011). This is something that is difficult to program into the software. For example, software might prompt students to respond *whether* they understand a problem, but a teacher can interpret *how* the students understand a problem. Getting the answers to these "how" questions demand a lot of interpretation capabilities and as discussed in the introduction, teachers have (at the moment) better capabilities for this than software does.

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