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Towards a theoretical understanding of learning with self-explanation prompts

Ida Bergvall & Anneli Dyrvold
Uppsala University

Oral or written requests to students to self-explain important aspects in a task at hand (e.g. self-explanation prompts) has proven to increase learning. Research about such prompts has mainly been introduced and discussed with cognitive perspectives focused on the individual. In this paper, we suggest an alternative theory, namely scaffolding theory grounded in a sociocultural perspective. Such a theory is valuable because it adapts to the individual learning process as well as to the learning process that takes place in group work. In addition, such a theory contributes valuable guidance to the teacher and to authors of teaching materials as well as to researchers in mathematics education. The theory is explained in relation to an example task, and an excerpt from student group work is discussed.

Introduction

Self-explanation prompts (SEPs), has previously been used and described as tools for teaching. SEPs are questions or elicitations that aim to induce meaningful explanations for oneself in an attempt to make sense of new information (e.g., Rittle-Johnson, Loehr, & Durkin, 2017). SEPs are most often used in textbooks, either as parts of the introduction when a new concept is introduced, or as a step in a step-by-step task. However, SEPs can also be used orally for example as an element of a lecture given by the teacher. The theoretical foundation for learning with SEPs has mainly been described within the frame of cognitive theories (e.g., Nokes, Hausmann, VanLehn, & Gershman, 2011; Rau, Aleven, & Rummel, 2017) or without any explicit theoretical frame (e.g., Corradi, Elen, & Clarebout, 2012; Eysink & de Jong, 2011). The aim of this paper is to propose a theoretical framing of self-explanation prompts and how they can enhance learning, based on the idea of scaffolding grounded in a sociocultural tradition and Vygotskij's zone of proximal development. The theoretical explanation suggested here, contribute a solid theoretical understanding of how learning occurs for individuals as well as in group work. A second aim is to create a foundation for well-informed teaching strategies, task design and analysis of students learning in research on SEPs. If there is a lack of a thorough theoretical understanding of the processes involved when working with a teaching strategy, it is easily happened that central prerequisites for the intended learning to occur are lost.

Self-explanation prompts

In mathematics, the prompted self-explanations can for example be about the meaning of a mathematical concept or a solution method. The purpose of the explanation is to clarify certain crucial aspects of the phenomenon of interest, connections between different parts, or links to previous knowledge, and thus strengthen one's own understanding in the learning situation (Berthold, Eysink & Renkl, 2009; McEldoon, Durkin & Rittle-Johnson, 2013). Self-explanations have proven effective to enhance learning (e.g. Rittle-Johnson, Loehr, & Durkin, 2017). However, self-explanations do most often not happen spontaneously (Schworm & Renkl, 2007) and therefore prompts to self-explain can be used.Despite the focus on self, SEPs can be used in group work because one person's self-explanation can constitute a piece towards the group's mutual inferences. By engaging in the explanation, central aspects are made clear to the individual, but are also made apparent to the whole group.

SEPs can be of various kinds and can be used for different purposes (see e.g., Dyrvold & Bergvall, 2019). One frequent purpose of SEPs described in previous research is as a means to foster conceptual understanding. By formulating SEPs as questions typically including a why-question or a prompt to discuss, students are encouraged to actively make inferences and construct arguments and thus strengthen their conceptual understanding. Another purpose is to support reading, mainly of multimodal texts. In this case, prompts could be designed as gap-filling tasks or questions prompting students to make inferences about the text and its content. Prompts aiming to support multimodal reading often support students in how to relate different parts of the text such as quantities to bars in a diagram (Dyrvold & Bergvall, 2019).

An example of a SEP aiming to foster conceptual understanding is given in the task "The Sunflower" below. The SEP is expressed by the sentence "First, discuss what it means for something to grow at the same rate every week". The SEP is supposed to support the students' understanding of "at the same rate" which is a crucial aspect of the concept of proportion. The intention with this SEP is to promote students' discussion of this central part and thus to support the students' development of conceptual understanding.

> Kim grows sunflowers during the summer holidays. The summer vacation is 7 weeks long. The sunflowers break through the soil just as the summer holidays begin and then grow at the same rate every week.
>
> First, discuss what it means for something to grow at the same rate every week.
>
> Task: One of Kim's sunflowers is 42 centimetres after the summer holidays. How high was the sunflower two weeks after school closure if it grew at the same rate every week?

Figure 1: The Sunflower.

Theoretical perspectives

This section starts with an overview of theoretical perspectives in previous research on SEPs. Thereafter we present a substantially different theoretical perspective which instead highlights how SEPs function as scaffolding and nurture fruitful interrelations between thought and language, individually and also in interaction. The alternative explanation of learning with SEPs is presented in two sections. First, the fundamentals of scaffolding theory are explained within this context and second, the sociocultural tradition with emphasis on thought and language is presented. Finally, this perspective is elaborated in relation to an example of a SEP which illustrate the contribution of this theoretical view.

Theoretical framing in previous studies about self-explanation prompts

In our reading of studies about SEPs, we have examined the theoretical framing in 42 recent studies focusing on SEPs, both within mathematics education and in other subjects. In these studies, a theoretical framing of SEPs is not always given or is only briefly elaborated. In studies without a pronounced theoretical argument for the SEPs, the SEPs may play a minor role in the investigation (e.g., Schalk, Schumacher, Barth, & Stern, 2018) or the theoretical emphasis is laid elsewhere in the study, such as on learning with multiple representations (Corradi, Elen, & Clarebout, 2012). There are also studies in which it is left to the reader to get a grip on the theoretical foundation that may be implicitly communicated through arguments for the use of SEPs such as to foster connections (Roelle & Berthold, 2013) or to support active learning and meaningful understanding (Neubrand & Harms, 2017).

In studies where the use of SEPs is based on explicit theoretical arguments, a common denominator is a cognitive perspective, a perspective that more or less turns the attention to the individual, not to the group and without any explicit explanation of the meaning of learning. The emphasis on cognitive perspectives in previous research can be traced back to the first studies within the area (e.g., Chi, Lewis, Reimann, & Glaser, 1989) and to several often quoted studies about SEPs, that largely have influenced the research field (Renkl, 1999). In particular, arguments for SEPs are often based on cognitive load theory (CLT) (e.g., Mwangi, & Sweller, 1998; Renkl & Atkinson, 2003). In short, CLT separates between different types of cognitive processes that may impose three main types of mental effort on students' working memory when they work with some learning material: intrinsic, extraneous and germane cognitive load. Intrinsic cognitive load stems from the inherent nature of the task at hand, a type of load that SEPs do not intend to alter. The focus in studies about SEPs are rathe r laid on extraneous (unwanted) cognitive load and germane cognitive load (that contributes to learning). SEPs can be used to reduce extraneous load (Sithole, Chandler, Abeysekera, & Paas, 2017) or to induce germane load (Berthold, Röder, Knörzer, Kessler, & Renkl, 2011) or both (Kern, & Crippen, 2017).

Besides the emphasis on CLT in studies on SEP, a constructivist theoretical base does also occur in several studies. For example, in a study by Roelle, Müller, Roelle and Berthold (2015) it is emphasized that the self-explanation activities are constructive since the learners must generate knowledge that goes beyond the provided information. Part of the goal with SEPs is also often that the students shall make inferences and revise existing knowledge, sometimes explicitly referred to as revising cognitive schemas, both in studies who have CLT as a theoretical frame and not. Cognitive schemas are also essential in Sweller's (1994) description of learning mechanisms within the CLT and accordingly the focus on schema acquisition and revision is yet another sign of the common cognitive ground within the current corpus of studies on SEPs.

In the current paper however, we suggest an alternative perspective namely a sociocultural theoretical framework which is useful as it provides tools for an in-depth understanding of how learning occurs during students' individual or collaborative work with SEPs. This framework has a twofold potential to explain how learning with SEPs occurs, first as scaffolding aiming to strengthen the thought by verbalizing the understanding of the content, and second by scaffolding and directing the students' attention to crucial aspects for example of a concept. These two sides of the theoretical explanation will be further developed below.

Theory on self-explanation prompts and scaffolding

According to sociocultural theory, development takes place through collaboration and imitation of how others solve advanced tasks. If you get help and guidance through collaboration, you can soon perform the tasks that you previously did not master. This difference between content that are familiar to a student and new content can be regarded as the zone of proximal development (ZPD) for the student (Vygotskij, 1978). In short, the ZPD has been described as the space that exists between a person's achieved level of knowledge where he or she can independently solve problems, and the possible development of knowledge that can occur in interaction and with support, for example from a teacher (Bakker et al., 2015). Such support of learning in the ZPD has been denoted as scaffolding. Scaffolding are often used as a metaphor describing support given by the teacher, but can also refer to support in the form of peer learning or by artefacts. Three characteristic features central to scaffolding have been described by van de Pol, Volman, and Beishuizen (2010), 1. *Contingency* - the scaffolding must be adapted to the student and his or her knowledge level. 2. *Fading* - the support provided by the scaffolding should be removed or faded as the student has attained the desired knowledge. 3. *Transfer of responsibility* - gradually, as the scaffolding is removed, the responsibility for the work is also transferred from the teacher to the student.

When taking a perspective on learning as scaffolded by SEPs, the SEPs are perceived as the means that contribute to raise understanding to a higher level. The prompt can provide students with support in identifying and directing focus to

crucial aspects. In this way SEPs act as part of the teacher's, or the more knowledgeable others, support in the ZPD. When the student formulates and puts his or her explanation into words, this explanation works as a scaffolding in the ZPD (Vygotskij, 1978), for the individual, as well as for peers when thoughts are made audible. The student's response to a SEP will also constitute scaffolding for other students in group work. In combination with preceding comments from other students, these responses do together create a conversation with the potential to scaffold learning within the ZDP. The connection between language and thinking as one of the crucial aspects of learning, supported by SEPs is elaborated in more detail below.

Theory on thought and language

Vygotsky (1986) discusses language and its role for thinking and learning and emphasizes the inner language and its significance for thinking. For young children, thinking develops by speaking loudly to themselves. This phenomenon has been referred to as an egocentric language. The egocentric language eventually develops into an inner silent language that, like the egocentric language, supports the thought. This development can be compared to a student who works with a SEP, and explains crucial aspects of the concept for himself or audibly to a peer student. Gradually, thinking evolves so that the verbal explanation becomes superfluous. Then the inner silent thought suffices as support. This transformation from the verbal explanation to the inner thought is essential in relation to how learning occurs when working with SEPs.

When it comes to scientific concepts, students' conceptual understanding is most often not fully developed when a concept is introduced during a lesson or in a textbook. The student first learns to recognize a particular word and thereafter an understanding of the meaning represented by the word is developed. Thereby the understanding of a scientific concept is developed from the general by making links to the concrete and well-known (Vygotsky, 1986). By using language individually and in collaboration with others, the student can create such links between the concrete understanding of a concept and the general scientific expression. In this perspective, this link is the basis for learning of scientific concepts (Vygotsky, 1986). The function of SEPs in relation to the development of conceptual understanding is to prompt the student to use the language to explain the concept, and thus making links to the well-known.

A learning situation when working with self-explanation prompts

In this section, we illuminate our perspective by an authentic example from three grade four students' collaborative work with a SEP. The example is derived from a larger project aiming at investigating students' learning during collaborative work with SEPs. The excerpt below shows the discussion during one group of students' joint work with the mathematical task "The Sunflower", described in

Figure 1. The task contains the SEP "First, discuss what it means for something to grow at the same rate every week". The aim of this SEP is to support the students' understanding of the concept of proportion. The concept is new to these students since the intention is to enable students to develop knowledge in their ZPD. In the design of a task or a learning situation, it is important that the students' understanding and previous knowledge are thoroughly taken into account (van de Pol et. al., 2010). If the match between the student's level of knowledge and the requirements in the task fails, the SEP will not work sufficiently.

The SEP encourages students to explain a crucial aspect of the concept. According to the theoretical framework described in this paper, the SEP aims to support the students' learning in two ways. First, the SEP fills the function to foster a verbal discussion and explanation of the targeted aspect. This verbalizing process creates a foundation for the students' learning through the connection between thought and language. Second, the SEP supports learning by directing focus to the formulation *the same rate*, which is a crucial aspect of the concept.

The following excerpt is an example of students' collaborative work with a SEP. The analysis of the excerpt based on the proposed socio cultural perspective elucidates the analytical potential of the theory. Our theoretical interpretation of the students' learning is explained in relation to the analysis below the excerpt.

1	Ally	What does it mean for something to grow at the same rate every week?
2	Ben	So all… all... maybe not all of them get the same length every time.
3	Ally	No.
4	Ben	But they increase the same. So that each plant, like if it was 10 centimetres, then it would be 20 more, so all of them would, would be, would be, 20 10 centimetres more even though they are not quite equally long.
5	Cris	Difficult to say…
6	Cris	You could say that it is like a staircase [shows steps with a gesture]. So you…
7	Ben	And each is 10 centimetres.
8	Cris	So it's like a staircase. It increases each time one step of 10.
9	Ben	Exactly! Something like that.

In line 2, Ben's utterance "maybe not all of them get the same length every time", reveal that the task is not too easy, and thus it is reasonable to assume that there is a potential for learning within the ZPD. If Ben was working alone, the task may have been too hard to solve, but in group work all students' verbalised thoughts became part of the scaffolding and the verbalised thoughts do therefore constitute

a kind of buffer that adjusts the difficulty to the students. This can for example be seen in line 4 - 7 where Ben and Cris further verbalises their developing thoughts about proportional growth. Ben tries out thoughts in line 2, thoughts that develops to a preliminary definition, "increase the same", in line 4. In line 5 Cris uncertainty reveals that the activities are within the ZPD even for him. He is unsure and uses a metaphor to describe his thoughts in line 6. This metaphor, "a staircase", do thereafter constitute a part of the scaffolding that supports Ben who further clarifies "each is 10 centimeters". In line 8 - 9 Cris and Ben agrees on a summary, which is interpreted as an expression of a new level of understanding since the utterances are more developed compared to the initial statements. The students build on each other's contributions and strive against a shared under-standing. The transcript does not reveal to which extent Ally is part of the discussion. It may be that the adaption between the SEP and Ally's level of understanding is poor (ibid.).

In summary, the SEP encourages the students to express their developing thoughts, thoughts that progresses from fragments to an appropriate description of proportionality in this particular case. So, the prompt function as scaffolding as well as the developing utterances and gestures do.

Implications for mathematics education

In this paper the idea of scaffolding grounded in a sociocultural tradition is suggested as a theoretical frame since it provides broader theoretical framework than cognitive theories. As illustrated in Figure 2 the suggested framework puts emphasis on two different aspects of learning that is nurtured by the SEPs namely to scaffold both structure and the relation thought – language. The theoretical frame is also applicable both for individual work and group work. The previous example about proportionality exemplifies an analysis of the scaffolding function of verbalised thoughts. However, a SEP does with necessity also provide structure, by directing the attention to the aspect the students are supposed to develop their understanding about. According to scaffolding theory this structure is supposed to be adapted to the learner's level of understanding, to be faded out and to be used in a deliberate way by the students. Such a match between the support given by the SEP and the students are briefly touched upon in relation to the example, in the interpretation of whether the students develop within their ZPD.

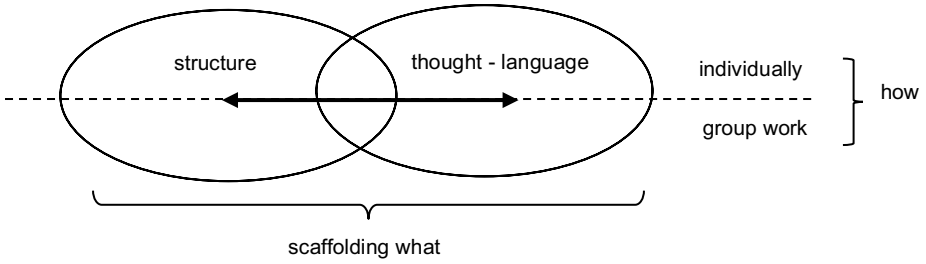

Figure 2: 'What' and 'how" self-explanation prompts can be scaffolding.

The suggested theoretical framework opens up possibilities for understanding and analysing learning in research on SEPS, and provides guidelines in the design of tasks and learning situations. For example, SEPs can be designed to support the development of multimodal reading competence where they provide structure by focusing attention to particular features of the text. The three distinguished characteristics of scaffolding: to be contingent, to be faded out, and to be used in a manner that transfers the responsibility to the learner (van de Pol et al., 2010), can be taken into account in task design, for example by successive prompts. The students then have the opportunity to take responsibility and choose the prompts that suits their level of understanding and the scaffolding function can reach its fullest potential. A perfect match between a SEP and a student group is not easily achieved, and dynamic scaffolding given by a teacher in relation to the expressed understanding can therefore be a useful calibrator during problem solving. With a good theoretical understanding, the teacher can act flexibly and adapt a SEP to the students' needs in the current situation.

Discussion

In this paper we have described a sociocultural theoretical framework for SEPs and how they can enhance learning. We thereby highlight opportunities to recognize and analyze potential of SEPs that might otherwise remain invisible. Our theory is in contrast to studies framed by cognitive load theory (CLT), where emphasis is put on the individual which corresponds to the upper left side of our model in Figure 2. In this way, the explanatory power of CLT is limited to an individualised learning process, and rather on how to guide the students towards what is to be interpreted (removing load), than to creating learning.

We argue that with the suggested sociocultural theoretical framework, more dimensions of the potential of SEPs are highlighted, which opens up new opportunities to understand, use and investigate this teaching tool. By using this framework, it is possible to illuminate how students can learn either individually or in groups. Learning is supported by SEPs pointing out key aspects, as well as by SEPs encouraging students to verbalise their thoughts. When students work individually with a SEP, they have to write down their answer, or answer orally for themselves instead of using language in interaction with their peer students. This is in line with the inner silent language, described by Vygotskij (1978). The analysis of the example also shows how this theory can provide a basis for understanding students' learning while working with SEPs.

In summary, the described framework provides improved possibilities for teaching, learning, and research on SEPs as described by the different spheres in the model in Figure 2.

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