Designing tasks with self-explanation prompts

Anneli Dyrvold & Ida Bergvall

Uppsala University; anneli.dyrvold@edu.uu.se; ida.bergvall@edu.uu.se

This paper presents some results from an ongoing review on self-explanation prompts. An emphasis is laid on design principles based on empirical research. The review is grounded in scaffolding theory, which means that the self-explanation prompts are seen as a temporary support that the student shall learn to manage without. Three themes identified in the review are described and discussed in relation to design and implementation of tasks with self-explanation prompts: prompts with different purposes, the necessity to adapt prompt to students' prior knowledge, and factors of importance for students' engagement in the prompts. Examples of tasks with prompts for which these design aspects have been taken into account are given in the paper.

Keywords: Scaffolding, ZPD, reading, multimodal, review.

Introduction

In mathematics classrooms, individual and group work on mathematical tasks is a frequent activity. Besides the mathematical complexity of the task, different design aspects also have bearing on students' learning. In this paper, we focus on design aspects concerning *self-explanation prompts* (hereafter SEPs), and how they can be used in tasks or instructions to scaffold students' learning.

The use of SEPs has been investigated in previous studies, often with pre- and post-tests, and some design aspects regarding SEPs have proven to be more effective than others when it comes to students learning (e.g., Berthold, Eysink & Renkl, 2009; Lin, Atkinson, Savenye & Nelson, 2016; Rau, Aleven, & Rummel, 2015). In this study, we utilize a qualitative perspective in order to highlight aspects concerning how tasks or instructions with self-explanation prompts can be successfully designed and used to scaffold students' learning in mathematics in relation to the zone of proximal development (ZPD). The study is based on an ongoing literature review of previous empirical studies on SEPs and their effectiveness. We also take a broad stance and include studies on SEPs in different subjects. A bottom-up perspective is used to search for prominent characteristics in the sample of studies on SEPs. More precisely, the following research question is answered in the current paper: *Which important aspects are there to consider in task design in order to scaffold students' learning in mathematics aided by self-explanation prompts?*

Studies on task design refer to either domain specific or domain transcendent aspects (Thanheiser, 2017). Domain specific aspects concern for example how tasks can be designed to support conceptual understanding. Domain transcendent aspects on the other hand takes a more interdisciplinary stance on, for example, reasoning, life skills, or reading of multimodal texts. In this paper, we focus on domain specific aspects with a focus on pupils' development of conceptual understanding, as well as on domain transcendent aspects, mainly regarding how SEPs can be used to support students' ability to read multimodal mathematical texts. In this study the emphasis is laid on the resources natural language, images, and mathematical notation.

Scaffolding and self-explanation prompts

Scaffolding is theoretically founded in a socio-cultural tradition. It is a metaphor which illustrates how people are assisted to reach learning goals that would not easily have been reached without scaffolding. In accordance with scaffolding theory, SEPs are meant to support learning in the zone of proximal development (ZPD) and therefore scaffolding needs to be adapted to the pupil and his or her needs and level of understanding. Another aspect of the scaffolding metaphor is that when the building is finished, that is, when the student has developed the targeted knowledge, the scaffolding needs to be removed. Finally, the scaffolding includes a transfer of responsibility from the teacher to the student (Bakker et al., 2015).

Traditionally, scaffolding has been referred to as the interaction between teacher and student, but the term was expanded to also include, for example, artefacts or instruction plans (Bakker et al., 2015). In the present paper, we study SEPs as a particular form of scaffolding of importance for task design.

In several previous studies, self-explanations are described as a successful means to increase students' knowledge and ability to solve problems (e.g., Chi, de Leeuw, Chiu & LaVancher, 1994; Rittle-Johnson, 2006). The self-explanations are explanations of a concept, a relation, or procedure given by the student to him or herself. SEPs has proved especially effective in subject areas such as mathematics and science, which often consist of general principles with few exceptions (Rittle-Johnson & Loehr, 2017). By explaining to oneself, it is possible to reconcile new information and to make inferences to prior knowledge (Chi et al., 1994; Berthold et al., 2009). What gives effect is the process to formulate an explanation, either to oneself or to others. Self-explanations however, are nothing that students usually do spontaneously and therefore prompts to self-explain have a large potential.

Method

The search for articles for the review has been limited to articles published after 2009. We both searched ERIC, with the search terms *self, explain*, and *prompt* and forward tracked selected key papers. Criteria for inclusion was a focus on prompts requesting students to self-explain while working on a typical written task or expository text. The collection of 41 relevant articles was analysed in an iterative process where categories were created and re-created based on what was revealed in the articles. Initially the articles were coded regarding choice of variables, method, and results, with a particular focus on how SEPs were defined and implemented. New categories both emerged and were dismissed based on what was eminent in the articles. The use of this iterative analysis resulted in a few final themes for which rich qualitative data could be derived from several of the analysed studies. Three of these themes are presented in the current paper.

Results

The answer to the question about which important aspects there are to consider in task design in order to scaffold student's learning in mathematics aided by SEPs is presented in three themes.

Theme 1: Using prompts for different purposes

Among studies that reveal positive effects of self-explanations, the prompts are used for three different purposes. Firstly, SEPs can scaffold the students in how to process the content and therefore enhance learning concerning domain specific aspects. The most prominent purpose is to encourage

inferences. Inferences are provoked by SEPs including a *why* question (e.g., Roelle & Berthold, 2013; Nokes et al., 2011) or by explicitly requesting arguments (Berthold et al., 2011). The advantage with SEPs that provoke inferences has also been revealed in comparisons with other SEPs (Roelle, Müller, Roelle, & Berthold, 2015; Neubrand & Harms, 2017). Inference prompts are superior for the acquisition of conceptual knowledge. It is evident that the *active* construction of the self-explanation is intrinsic since other prompts given in combination with explanations of the inferences requested by the inference prompts are less beneficial (Roelle et al., 2015).

Secondly, SEPs can be used in a domain transcendent manner to support reading, and therefore enhance learning. SEPs focusing on reading have shown positive effects on learning outcomes when the SEPs are designed to induce focused processing of the text and to avoid shallow reading. For example, SEPs providing reading guidance in terms of higher order questions that require the learner to actively generate inferences about unfamiliar content, have proven to be effective means to develop conceptual knowledge (Roelle & Berthold, 2013). Gap-filling prompts that support reading by prompting the student to make inferences and by that add coherence to the text, also lead to greater learning, as shown by Nokes, Hausmann, VanLehn, and Gershman (2011). Particularly effective are step focused prompts, supporting students in the reading by drawing attention to each step in an example, with prompts to explain, elaborate and summarize (ibid.). Studies that evaluate the use of SEPs in multimodal text reveal different benefits in relation to the use of such prompts. When reading multimodal text, it is intrinsic to understand how the different representations relate and SEPs can successfully facilitate such an understanding. SEPs can scaffold the reading by prompting the reader to relate parts of, and explain relations within the text (Rau et al., 2015) as exemplified in Figure 1.

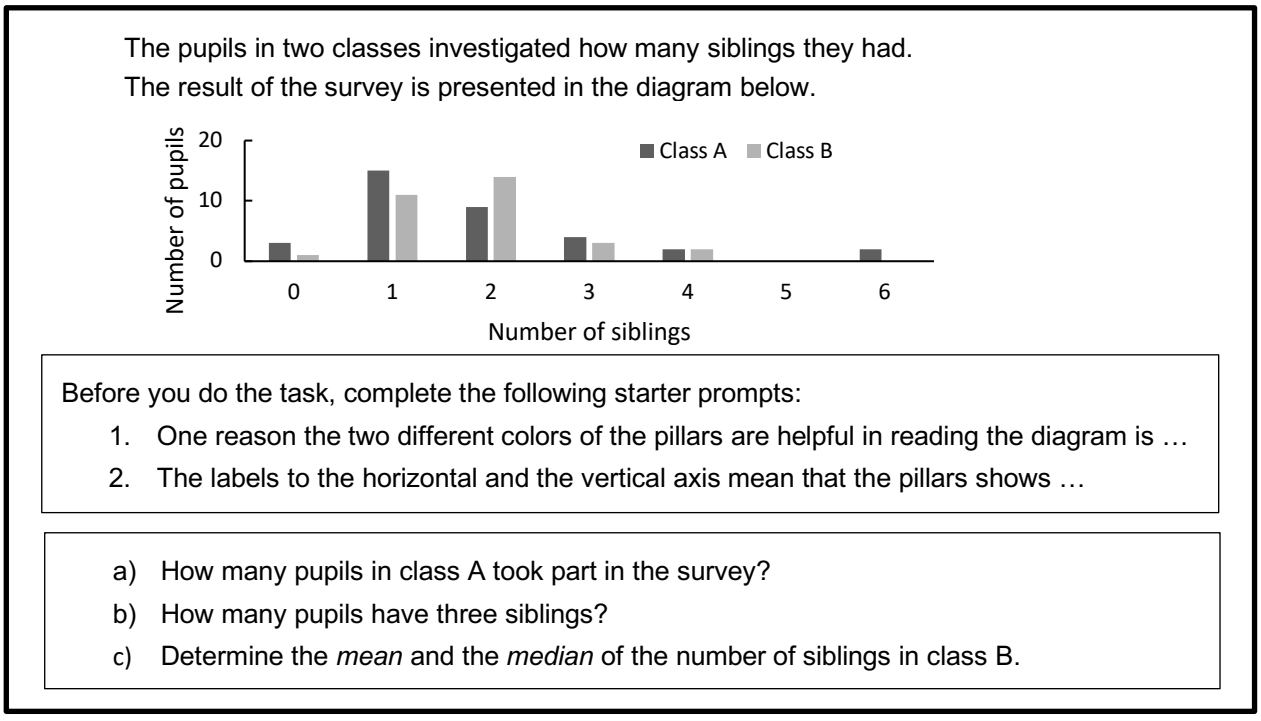


Figure 1: *Open-ended prompts to make inferences and to relate between modalities*

For example, the student can be prompted to self-explain which perceptual features of graphic representations that depict corresponding concepts and complementary information (Rau et al., 2015).

Such prompts to relate and translate between representations lead to better learning results compared to general prompts to self-explain (e.g. 'explain your answer') (van der Meij & de Jong, 2011). SEPs are particularly useful when many representations must be related to deeply understand key concepts (Rau et al., 2015). Figure 1 is an example of how prompts can be used to support reading of multi-modal texts. The first prompt draws attention to how the bars in two different colours represent the two classes mentioned in the text. The second prompt foster attention to the meaning of the axes in the graphic representation and demand the reader to relate information given in natural language and visually. The knowledge of how to read and understand the various parts of the diagram is essential.

Lastly, SEPs can diminish the cognitive load and therefore contribute to the fulfilment of the first two purposes (support reading and processing of the content). If SEPs are designed to guide the attention to relevant principles in a text, extraneous cognitive load can be decreased, and as a result, learning can be improved (Wang & Adesope, 2017). There is however a potential opposite effect; SEPs can increase extraneous cognitive load if they do not suit the reader, for example if the prior knowledge is high and the prompted inferences therefore are perceived as redundant and distracting.

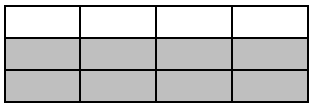
Theme 2: Adaptation of prompts to students' prior knowledge

The positive outcomes from the work with SEPs is dependent on the match between the student and the prompt. In particular, the students' prior knowledge is crucial. For example, prompts to make inferences are demanding. Neubrand and Harms (2017), who categorizes inference building prompts as high-knowledge prompts, do however reveal that even for medium knowledge learners the most positive impact with regard to quality of SEPs is created by using a combination of less demanding prompts (paraphrasing, recourse of previously given information, searching for relevant relations between parts of the text) and high demanding prompts (anticipative, inference-building and with recourse to prior knowledge).

In some studies, interventions with SEPs do not lead to better learning outcomes than for the control group. One possible explanation for the lack of effect of SEPs is either that the knowledge level with abstract concepts is too high for the students (Hsu & Tsai, 2013), or that the level is too low and that the prompted self-explanations hinder the students in their work (Roelle & Berthold, 2013). In a socio-cultural perspective, this can be understood as if the concepts are not held within the students' ZPD. If the new information is at an overly high level, the students will not have the opportunity to make the connections between new information and previous knowledge, which are required for learning. The intended effect of SEPs can also be missing if the level of the concepts or procedures that students should develop is too low. In a study by Neubrand et al., (2016) it appeared that worked examples (WE) with SEPs are effective for students with medium-level of prior knowledge. For students with good knowledge of the subject, WE with SEPs were negative for learning outcomes, no matter how they were designed. SEPs then presents a disadvantage for the students since the previous knowledge and the information given in the WE simply becomes redundant and perhaps boring or distracting. Figure 2 shows a task with different prompt options which can be used for students at different levels of knowledge.

a) Calculate the product of $\frac{3}{4}$ and $\frac{2}{3}$

b) The rectangle represents the whole. Use the rectangle to illustrate the product $\frac{3}{4} \cdot \frac{2}{3}$



Prompt version 1

The grey part of the rectangle represents $\frac{2}{3}$. Try to mark $\frac{3}{4}$ of the whole rectangle with dots in such a way that $\frac{3}{4}$ of the grey area are dotted at the same time. The dotted grey area represents $\frac{3}{4}$ of $\frac{2}{3}$ and also the product of the fractions. Why?

Prompt version 2

You know that $3 \cdot \frac{2}{3}$ can be interpreted as taking $\frac{2}{3}$ three times. It is however difficult to imagine taking something $\frac{3}{4}$ times (as in the task). Use your illustration and explain what the multiplicator $\frac{3}{4}$ means and how your explanation relates to 3 in the product $3 \cdot \frac{2}{3}$

Figure 2: *Task with two versions of self-explanation prompts*

The first version of a prompt is intended for students with less prior knowledge. Students who are very unfamiliar with this type of task can also be given a worked example with a starter prompt. Version 1 gives more scaffolding and gives recourse to representations in the task and is therefore adapted to less prior knowledge. Version 2 offers less scaffolding, and encourages the student to use prior knowledge while making inferences and is therefore adapted to medium to high prior knowledge.

Theme 3: Designing tasks and self-explanation prompts that engage students

A crucial factor in achieving the intended outcome from the use of SEPs is student engagement in the explanations. In several studies (e.g., Hsu & Tsai, 2013) the students' answers to the given SEPs were not sufficiently well processed and the quality was insufficient. However, the results in these studies also showed that students who actually produced well-developed and high-quality responses also showed good results in the post-test. The reasons why students did not engage in the SEPs varied. Pre-formulated self-explanations in a game environment for primary school children is one example of SEPs that was not sufficiently engaging for students to give any effect on learning (Hsu & Tsai, 2013). Another reason for students not to engage actively in the work with SEPs was that the students experienced the SEPs as demanding and simply skipped them (Lin et al., 2016).

Students' lack of engagement in SEPs can also be explained by the extensiveness of the SEPs. In a study by Kapli (2010), no effect on conceptual knowledge or problem solving performance were found if SEPs were given together with supportive instructions. The scaffolding given by the SEPs was however not gradually faded out, rather the scaffolding was continuously accessible for the students. This may have had the effect that students did not take sufficient effort to understand the concepts; instead, they could use the support at any time. However, the study also showed a positive correlation between quality in the students' self-explanations and the acquisition of conceptual knowledge.

Figure 2 is sufficient as an example of design aspects in relation to student engagement, since there is a relation between prior knowledge and student engagement in a task. With prompt options a student can choose no prompt, or prompts adjusted to more or less prior knowledge and to their willingness to engage in deep learning in a particular task. In accordance with theory about scaffolding, students are supposed to learn to manage by themselves what the prompts scaffold and therefore one

optional version of a prompt is not always sufficient. In Figure 1, the student needs to take an active role in constructing the knowledge requested by the SEPs, which might be engaging. If the prompts on the other hand were formulated as multiple choice alternatives the prompts are likely to be less engaging (see e.g., Hsu & Tsai, 2013).

Discussion

The current paper contributes to previous research on SEPs with a qualitative perspective and a focus on design aspects. The design of tasks with SEPs is done in relation to a target group, but the usefulness of a particular prompt can vary between students in a class and therefore our results is applicable also in relation to the implementation of the prompted tasks. We argue the usefulness of SEPs is dependent on a match between the task, the prompt, and the student. This interrelation is relevant in relation to all three themes presented in the paper.

It is also apparent that the three presented themes are related. Theme 1 about the prompt's purpose is related to both the other themes since the purpose must be taken into account when prior knowledge and students' engagement are considered. Theme 2 and theme 3 are also interrelated since engagement is often dependent on prior knowledge. This means the adaptation to all three themes in design of SEPs could be highly beneficial in providing opportunities for learning, when they are combined and taken into account simultaneously. Figure 3 illustrates how the three themes overlap in a common intersection. According to the results of this study, tasks that can be described as belonging in this intersection, offer the best opportunities for learning.

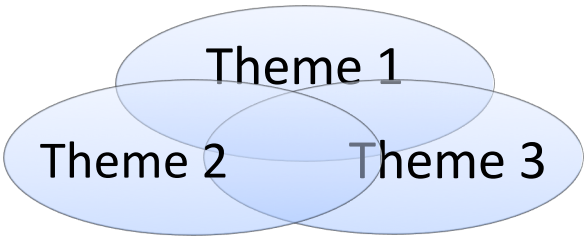


Figure 3: *Three interrelated themes, appropriate to consider together*

In the everyday practice when using SEPs in mathematics there is several aspects to consider. Firstly, SEPs can scaffold different types of learning and the teacher, or task designer, must know what he or she intends to achieve with SEPs. Students may benefit from SEPs when new concepts are introduced since the SEPs support them in integrating knowledge to what they have learnt previously (e.g., Nokes et al., 2011) and from SEPs that support reading text with different representations of a concept (e.g., Rau et al., 2015).

Secondly, the SEPs must be adapted to students' prior knowledge that is relevant in relation to the content of the mathematics text. Since prior knowledge vary in a group of students we argue for a flexibility in the use of SEPs, both by utilizing variants of SEPs (Figure 2) and by encouraging students to be flexible in the use of SEPs in such a way that they will only be used when needed. As the students develop their understanding, the SEPs need to be taken away since scaffolding shall be seen

as a temporary support when new abilities and knowledge are developed (Bakker et al., 2015). Such an adaptation to the students is important also since redundant SEPs may increase the cognitive load or distract students and accordingly the teacher needs awareness of this.

Thirdly, SEPs are effective only if students engage thoroughly in the self-explanations. As mentioned previously the fit between students' knowledge and the SEPs is crucial if the SEPs shall lead to the intended learning (Neubrand & Harms, 2017) and too demanding or too trivial prompts can reduce students' commitment to the SEPs. SEPs to make inferences are demanding but also very efficient. An implication for teaching is thus that students need to be given the opportunity to practice more demanding self-explanation in classroom. Students may need to practice on how to formulate appropriate answers to these types of prompts, and to get feedback on their answers. In this way, students can understand what is expected and also understand that the answers are important, which can motivate students to work with their answers to make them high quality.

Lastly, when working with SEPs it is important to bear in mind that the scaffolding has to fade out as students' knowledge increase. This can be done in different ways. In teaching materials, scaffolding ought to be used in tasks initiating a new topic or concept and in such occasions the scaffolding fills a function, for example, in supporting reading of multimodal texts. As the teaching proceeds and the students improve their ability to read multimodal text, the scaffolding become superfluous. It is also possible for the teacher to take an active role in the use of scaffolding, by carefully following the development of the students' knowledge in order to use SEPs only to students considered in need for this support. To conclude, we see a large potential in the use of SEPs but the design of prompts and the adjustments to the student group is a delicate task to achieve the intended learning.

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