Using Example-based PF Conditions to Investigate Preparatory Effects of Problem-solving Prior to Instruction

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Abstract: Research on the effectiveness of Productive Failure has demonstrated that prompting students to solve a problem before they get instruction about the canonical solution, aids their learning compared to getting instruction first, even if they generate incomplete or erroneous solutions. However, it is still unclear how failing to solve a problem prior to instruction prepares students for learning. In two studies, we used example-based conditions to investigate preparatory effects of problem-solving prior to instruction.

Introduction

One theoretical explanation for the beneficial effects of the Productive Failure (PF) approach highlights developing an awareness of knowledge gaps as an essential preparatory mechanism of the initial problem-solving phase in PF (Loibl & Rummel, 2014). When students produce erroneous solutions prior to instruction, they may become aware of the flaws of their solution attempts during the problem-solving process. This could then make them more receptive to the subsequent instruction. As was shown by Loibl and Rummel (2014), students learn more from the instruction after the initial PF problem-solving phase, if the instruction uses erroneous student ideas as a starting point for explaining the canonical solution. This finding supports the notion that students first need to become aware of the shortcomings of their knowledge in order for instruction to successfully overcome those. The awareness of knowledge gaps may be established at the outset of instruction (Loibl & Rummel, 2014) or before, through experiences of failure during the initial problem-solving phase of PF. Research has not yet established the link between students' awareness of knowledge gaps during the initial problem-solving phase and their learning from the subsequent instruction. This lack of empirical evidence can be explained by the high diversity of students' problem-solving attempts. When students solve a problem prior to instruction, they generate a different quantity and quality of solutions. Examining the impact of the awareness of knowledge gaps is thus challenging, because the solution number and quality may affect to what extent students can become aware of their knowledge gaps. For instance, if a student only generates one or two solutions there might be fewer opportunities for becoming aware of solution limitations (and thus of associated knowledge gaps), than if he/she generates a higher number of solutions. In order to examine the impact of knowledge gap awareness on learning from PF, the number and quality of student solutions need to be experimentally controlled. A promising methodological approach to handle this challenge could be to use example-based PF conditions. In an example-based PF condition, students observe solutions created by other PF students without generating own solutions. This allows to control for the number and quality problem-solving attempts students are faced with in the initial phase of PF (i.e. prior to instruction). Furthermore, example-based conditions can be varied to test additional hypotheses: one relevant question is whether students gain a higher awareness of knowledge gaps and thus benefit more from the subsequent instruction when they a) observe the entire problem-solving process of the model PF student, who is becoming aware of his/her knowledge gaps ($EX_{process}$), or b) whether it is sufficient for them to learn from the final solutions of the model PF student ($EX_{solution}$). One limitation of example-based PF conditions could be that observing a failing student in developing awareness of knowledge gaps has a lower impact on student learning, than experiencing one's own failure. However, Kapur (2014) found that observing solutions created by other students also prepares students for the subsequent instruction. Although the observing students gained less from the instruction than students who experienced own failure, the example-based condition outperformed a direct-instruction condition, which is the usual control condition for PF. When the examples do not only include the final solution, but the process of attempting to solve the problem, benefits of observing PF might be stronger.

Methods

In two studies at secondary schools in Germany, we implemented example-based PF conditions to investigate whether students need to become aware of their knowledge gaps prior to instruction. Study 1 had a quasi-experimental design with four conditions (PF, two example-based PF conditions, direct Instruction; $N = 75$; $M_{age} = 16.08$, $SD = 1.87$). Study 2 had an experimental design with three conditions (PF, two example-based PF conditions; $N = 177$; $M_{age} = 16.06$, $SD = .76$). In this paper, we zoom in on the two example-based PF conditions. In Study 1, the students in the PF-condition produced solutions on tablet-PCs while thinking aloud. By recording this process (video and audio recordings), we created the content for our example-based PF conditions. Only the audio recordings include process information about the PF student's awareness of knowledge gaps. In one example-based PF condition ($EX_{process}$), students' observed the full process of how a PF student generated solutions (video) and what the PF model said while thinking aloud (audio), whereas in the other example-based PF condition ($EX_{solution}$), the students only viewed the final solutions of a PF-student (picture). After studying the PF examples, the students of both conditions received an instruction about the canonical solution, followed by a knowledge post-test (conceptual and procedural knowledge). We hypothesized that the $EX_{process}$ condition, in which students have access to the model's knowledge gap awareness (displayed by the processes), leads to better conceptual knowledge than displaying only the final solutions to students ($EX_{solution}$).

Results

Although students of the $EX_{process}$ condition descriptively outperformed the $EX_{solution}$ condition in both studies (see *Table 1*), Mann-Whitney U tests revealed no significant differences for conceptual knowledge in Study 1 ($U = 110.5$, $p = .371$), or study 2 ($U = 1433.0$, $p = .074$).

Table 1: Descriptive statistics for post-test scores on knowledge (Study 1 & Study 2)

Study 1		*Conceptual & Procedural (max. 12 points)*	*Conceptual (max. 7 points)*	*Procedural (max. 5 points)*
Condition	N	MEAN (SD)	MEAN (SD)	MEAN (SD)
$EX_{process}$	15	6.03 (2.47)	2.43 (1.62)	3.60 (1.56)
$EX_{solution}$	18	5.61 (2.46)	1.94 (1.55)	3.67 (1.50)
TOTAL	33	5.80 (2.44)	2.17 (1.58)	3.64 (1.51)
Study 2				
$EX_{process}$	57	5.50 (3.11)	2.99 (1.48)	2.51(1.99)
$EX_{solution}$	62	4.94 (3.21)	2.52 (1.78)	2.42 (1.92)
TOTAL	119	5.21 (3.16)	2.74 (1.65)	2.46 (1.95)

Additional analyses revealed, that students' (self-reported) awareness of knowledge gaps after studying the PF examples did not significantly differ among the $EX_{process}$ ($M = 2.07$; $SD = .99$) and the $EX_{solution}$ condition ($M = 2.15$; $SD = .91$) as revealed by a T-Test ($t(117) = -.476$, $p = .635$). Looking at each condition separately, we found a significant correlation between students' perceived competence and their conceptual knowledge for $EX_{process}$ ($r_s = .417$, $p < .01$), but not for $EX_{solution}$ ($r_s = -.037$, $p = .780$). Therefore, students in the $EX_{process}$ condition seem to assess their competence more accurately according to their post-test performance.

Discussion

Contrary to our hypotheses, the results of both studies do not support the assumption that displaying process information prepares $EX_{process}$ students more effectively for instruction than observing only the outcome of PF. Furthermore, the two example-based PF conditions did not differ in their self-reported awareness of knowledge gaps. As shown by Loibl and Rummel (2014), contrasting incorrect student ideas with the canonical solution showed much stronger effects on learning than problem solving first, and being instructed afterwards, but without using incorrect student ideas during this instruction. Because $EX_{process}$ as well as $EX_{solution}$ obtained an instruction with contrasting incorrect student ideas, it may be sufficient to only provide solutions in the first place to aid learning. However, we found differences regarding the perceived competence among students in the in the two example-based PF conditions, which hint at beneficial effects of observing process information. Our analyses revealed that only if students have access to the entire problem-solving process ($EX_{process}$), the perceived competence positively correlated with students' performance on the post-test. Students who had access to the entire problem-solving process therefore seem to assess their learning more accurately according to their post-test performance, which at least partially supports the assumption that being aware of knowledge gaps prepares students for the subsequent instruction.

References

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