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Completion problems can reduce the illusions of understanding in a computer-based learning environment on genetics

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ABSTRACT

Inaccurate judgments of task difficulty and invested mental effort may negatively affect how accurate students monitor their own performance. When students are not able to accurately monitor their own performance, they cannot control their learning effectively (e.g., allocate adequate mental effort and study time). Although students' judgments of task difficulty and invested mental effort are closely related to their study behaviors, it is still an open question how the accuracy of these judgments can be improved in learning from problem solving. The present study focused on the impact of three types of instructional support on the accuracy of students' judgments of difficulty and invested mental effort in relation to their performance while learning genetics in a computer-based environment. Sixty-seven university students with different prior knowledge received either incomplete worked-out examples, completion problems, or conventional problems. Results indicated that lower prior knowledge students performed better with completion problems, while higher prior knowledge students performed better with conventional problems. Incomplete worked-out examples resulted in an overestimation of performance, that is, an illusion of understanding, whereas completion and conventional problems showed neither over- nor underestimation. The findings suggest that completion problems can be used to avoid students' misjudgments of their competencies.

1. Introduction

Worked-out examples (i.e., step-by-step demonstrations of how to solve a problem) have been shown to be beneficial for students' learning (e.g., Atkinson, Derry, Renkl, & Wortham, 2000; Renkl & Atkinson, 2003). However, as a side effect, complete as well as incomplete worked-out examples may lead to an overestimation of competence, which can be referred to as an illusion of understanding with potentially negative effects on the regulation of learning processes (Baars, Visser, Van Gog, de Bruin, & Paas, 2013; Renkl, 2002). Because illusions of understanding might emerge from inaccurate judgments regarding the processing demands of the tasks (e.g., feelings of difficulty; Efklides, 2006), an important question is how the accuracy of these judgments can be improved. Therefore, the purpose of this study was to investigate whether, besides different levels of learning performance, illusions of understanding are more likely to occur with high instructional support (i.e., incomplete worked-out examples) and less likely with reduced amount of support (i.e., completion and conventional problems) while learning genetics within a computer-based learning environment (CBLE).

1.1. Types of instructional support in learning from problem solving

An important prerequisite for achievement in knowledge-rich domains such as mathematics and science while using CBLEs is the acquisition of problem-solving schemas (i.e., representations of specific problem categories with the corresponding solving procedures; VanLehn, 1989; see also Sweller, Van Merriënboer, & Paas, 1998). The acquisition of problem schemas is facilitated when students learn from worked-out examples rather than from traditional problem solving without any support (i.e., conventional problems), at least in the initial skill acquisition phase (e.g., Van Gog, Kester, & Paas, 2011).

In learning from problem solving, one can think of a continuum of instructional support ranging from complete worked-out examples (via incomplete worked-out examples and completion problems as intermediate types of support) up to conventional problems. Whereas complete worked-out examples provide students with

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full support, consisting of a description of the problem state (i.e., the given state), the solution steps, and the final solution itself (i.e., goal statement), conventional problems provide only a description of the problem state together with the goal statement, and students have to complete the solution steps themselves. Numerous studies have shown that instruction using properly designed worked-out examples is more effective (i.e., leads to higher performance) and efficient (i.e., higher performance combined with lower learning time and/or mental effort) than instruction consisting of conventional problems (for overviews, see Atkinson et al., 2000; Renkl, Hilbert, & Schworm, 2009; Van Gog & Rummel, 2010). This is known as the so-called *worked example effect* and represents one of the classical instructional effects emphasized by cognitive load theory (Sweller, Ayres, & Kalyuga, 2011; Sweller et al., 1998).

According to cognitive load theory, worked-out examples free up the necessary cognitive resources by reducing unproductive search processes, and thus enhance students' acquisition of problem-solving schemata (Sweller, 1999; Sweller et al., 1998; Van Gog et al., 2011), which can eventually be applied flexibly to other problems. Conventional problems, on the contrary, require students to employ general problem-solving strategies (e.g., means–ends analysis), which can cause excessive cognitive load and, as a result, hinder the acquisition of problem-solving schemata (Renkl et al., 2009; Van Gog et al., 2011).

Cognitive load defined as the burden imposed on students' working memory capacity by solving a given problem is typically assessed by measuring subjective invested mental effort and perceived task difficulty (Paas & Van Merriënboer, 1994; see also Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Although perceived task difficulty and invested mental effort are related (e.g., Efklides, 2006), they are different from a cognitive load theory perspective (Van Gog & Paas, 2008). Perceived task difficulty reflects mainly the demands of the tasks, that is, intrinsic load (i.e., element interactivity of the tasks; Van Gog & Paas, 2008, see also Kalyuga, Chandler, & Sweller, 1999). When dealing with a task, students perceive the demands of that task (i.e., the required effort to solve that specific task) and react with an investment of mental effort to this perception. Therefore, invested mental effort can be seen as a function of perceived difficulty of the tasks, and defined as the cognitive resources allocated to deal with the demands imposed by a given task (Paas et al., 2003). It has been shown that mental effort invested in a task is primarily influenced by the perceived difficulty of that task (e.g., Efklides, 2006), with higher perceived task difficulty resulting in a greater investment of mental effort (Brünken, Plass, & Leutner, 2003). However, the positive relationship between ratings of perceived task difficulty and invested mental effort may not always exist, because students may decide to invest low mental effort even though they perceive the difficulty of the task as being high (cf., Van Gog & Paas, 2008). The lack of correspondence between the two constructs occurs more often at the higher extreme of task difficulty continuum: when students perceive a task as being extremely difficult, they lack the confidence in their ability to solve that task and, as a result, they are not motivated to invest mental effort in solving the task (e.g., Bandura, 1989; Paas, Tuovinen, Van Merriënboer, & Darabi, 2005; Pintrich & Schrauben, 1992).

Empirical evidence regarding the question whether learning from conventional problems should be replaced by studying full worked-out examples has lead to contradictory results (e.g., Kalyuga, Chandler, Tuovinen, & Sweller, 2001; Van Merriënboer & Sweller, 2005). For example, some researchers have shown that worked-out examples cause *illusions of understanding* because students often simply acknowledge the information presented by the completed solution steps without trying to deeply understand or elaborate on it (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 2002). Therefore, providing only worked-out examples could be insufficient to improve learning due to the danger of inducing shallow processing (see Paas & Van Gog, 2006). Deeper processing of full worked-out examples might be accomplished only when students know *how* and *when* to elaborate on the completed solutions steps or when they self-explain the underlying principles on which those solutions are based (i.e., principle-based explanations; Renkl, 1999). For example, Chi et al. (1989) found that students who spontaneously generated a higher number of self-explanations while studying full worked-out examples obtained a better performance than students who generated fewer self-explanations (i.e., *self-explanation effect*). In addition, Renkl (1997) found that many students were passive or superficial explainers while studying full worked-out examples, and that among the active explainers the most successful ones were those who explained the worked-out examples based on the fundamental principles of the domain.

Given the evidence that many students are passive explainers while studying worked-out solution steps, researchers have recently focused on different instructional methods to improve learning from full worked-out examples. *Incomplete worked-out examples*, in which one or a few steps were omitted, have been shown to be more effective than full worked-out examples in which all steps were presented (e.g., Renkl, 2002; Stark, 1999). For example, Stark (1999) compared incomplete worked-out examples with full worked-out examples and found that the insertion of "blanks" into the sequence of solution steps (making the solution partially incomplete) prompted students' self-explanations, which in turn fostered their learning. These findings are explained by the fact that the insertion of "blanks" in the solution steps require students to anticipate the missing steps and, as a result, they engage more deeply and actively in processing the worked-out solution steps (e.g., Renkl, 2002).

Contrary to incomplete worked examples that provide an almost complete solution (i.e., just one step or a few steps are omitted), completion problems provide a partial solution with more than just a few solution steps omitted (Van Merriënboer & de Croock, 1992; Van Merriënboer, Schuurman, de Croock, & Paas, 2002). In terms of the continuum of instructional support mentioned above, completion problems correspond to an intermediate type of support between incomplete worked-out examples and conventional problems.

Similar to incomplete worked-out examples, completion problems stimulate students to process the worked-out solution steps more deeply, and thus enable them to acquire more complex cognitive schemas (i.e., the so-called *completion problem effect*; Van Merriënboer & Sweller, 2005). Several studies have shown that completion problems are more effective than both full worked-out examples and conventional problems in facilitating transfer (e.g., Renkl, 2002; Renkl & Atkinson, 2003; Stark, 1999; Van Merriënboer & de Croock, 1992). In addition to facilitating transfer, completion problems as well as incomplete worked-out examples can be assumed to reduce illusions of understanding, because students have to solve at least parts of the solutions by themselves and, thus, need to process the solutions more deeply. However, this assumption has not yet been tested empirically.

Deeper processing of full worked-out examples can also be fostered by making sub-goals more explicit through labeling or visually isolating the different solution steps. When the solution steps are emphasized by labeling or visually isolating them according to the sub-goal learning model (Catrambone, 1995, 1996), students are more likely to self-explain how these steps are connected and contribute to the final solution, which in turn promotes successful learning (see also Renkl et al., 2009). Catrambone (1995, 1996) found that students who learned from worked-out examples that emphasize the sub-goals by explicitly labeling the solution steps performed better than students who learned from conventional worked-out examples.

The effectiveness of different types of instructional support such as full worked-out examples or completion problems depends on