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How to sequence video modeling examples and inquiry tasks to foster scientific reasoning

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ABSTRACT

Scientific reasoning skills can be acquired through technology-enhanced inquiry tasks or video modeling examples showing how to conduct virtual experiments. However, inquiry tasks can be cognitively demanding for novice learners, whereas video modeling examples can induce overconfidence. The present study investigated the effectiveness of both approaches in isolation and combination. We compared the effects of four groups (example-example, example-task, task-example and task-task) on learning outcomes, perceived difficulty and mental effort, judgments of learning, and monitoring accuracy among 107 seventh graders. In line with our hypotheses, watching a video modeling example first led to lower mental effort, better learning outcomes, and higher judgments of learning than solving an inquiry task first. Contrary to our hypotheses, all groups underestimated their performance. Results for mental effort and learning outcomes corroborate research on worked examples, whereas results for judgments of learning and monitoring accuracy indicate an underconfidence-with-practice effect.

1. Introduction

Scientific reasoning is a vital aspect of international science education standards (National Research Council, 2012; OECD, 2007). It involves the skills implicated in generating hypotheses, designing experiments, and evaluating evidence (C. Zimmerman, 2007). A core component of scientific reasoning is the ability to design controlled experiments and evaluate the resulting evidence with regard to one's hypotheses. This aspect is addressed in the *control-of-variables strategy* (CVS; Chen & Klahr, 1999). It states that all variables except the one being tested should be held constant across experimental trials to yield conclusive results. However, this strategy can be difficult to apply, especially for younger students (Piekny, Grube, & Maehler, 2014; Piekny & Maehler, 2013). The CVS does not develop routinely as a consequence of mere exposure to everyday situations that require scientific reasoning; rather it has to be the subject of science teaching (C. Zimmerman, 2007). The present paper deals with the question of how to best convey the CVS by making reference to two prominent teaching approaches, namely, inquiry learning with virtual experiments (de Jong, 2006) as well as example-based learning with video modeling examples (Mulder, Lazonder, & de Jong, 2014). Unfortunately, both approaches are not only associated with specific benefits for learning; they also come along with particular challenges: Pure inquiry learning can be cognitively overwhelming, particularly for novice learners, whereas studying examples can induce illusions of understanding, which might impede learning (Baars, van Gog, de Bruin, & Paas, 2016). In the present study, we contrasted combinations of the two approaches with learning from just one approach to test whether the former would help to balance out the negative side effects of each approach while making use of the benefits. Because combining inquiry tasks with video modeling examples raises the question of how to sequence these learning activities (i.e., presenting examples before or after inquiry tasks), this question was additionally addressed in the paper.

1.1. Inquiry learning

One prominent instructional approach to fostering the acquisition of scientific reasoning is inquiry learning (Lazonder & Harmsen, 2016). During inquiry learning, students “conduct experiments, make observations, or collect information in order to infer the principles underlying a topic or domain” (Lazonder & Harmsen, 2016, p. 2). Inquiry learning is applied in schools to

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teach science content and also science process skills such as scientific reasoning (Lazonder & Harmsen, 2016). The recent advent of computer simulations allows students to investigate a wide range of scientific phenomena by manipulating variables that would not be easily accessible in physical experiments (de Jong, 2006).

However, unguided inquiry tasks generally are an inefficient way to enhance children's use of the CVS (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011). Novice learners, especially, often do not profit from unguided inquiry learning, which can be seen as an ill-defined problem solving activity (C. Zimmerman, 2007). Problem solving requires learners to handle a large number of information elements simultaneously, which may overwhelm students' limited cognitive resources (Sweller, van Merriënboer, & Paas, 1998; Tuovinen & Sweller, 1999). This is especially true for novices who lack schemata that would guide their problem solving. Therefore, students need guidance to focus their limited cognitive resources on the most relevant information and acquire problem-solving schemata (Tuovinen & Sweller, 1999).

With appropriate guidance, inquiry learning can be more effective than expository methods, which is consistently shown in meta-analytic studies (e.g., Alfieri et al., 2011; Lazonder & Harmsen, 2016). Different types of learner guidance have been proven effective to learn the CVS, for instance, direct instruction (Klahr & Nigam, 2005), experimentation hints (Kuhn & Dean, 2005), task structuring (Lazonder & Kamp, 2012), and worked examples (Mulder et al., 2014). Mulder et al. (2014) used video modeling examples to show students how to conduct virtual experiments in an inquiry learning environment. Students presented with modeling examples displayed superior inquiry behavior than students who did not receive video modeling examples. This result can be explained with the worked example effect.

1.2. Example-based learning

According to the worked example effect, it is beneficial for novice learners to study worked examples containing a step-by-step expert solution to a problem before solving a task on their own (Cooper & Sweller, 1987; Sweller & Cooper, 1985). Studying an example instead of solving a problem reduces unnecessary cognitive load. Thus, learners can use their working memory resources to build a problem-solving schema for later problem-solving situations (Cooper & Sweller, 1987). The worked example effect has been shown in diverse contexts such as algebra (Sweller & Cooper, 1985), programming (Kalyuga, Chandler, Tuovinen, & Sweller, 2001) and scientific reasoning (Mulder et al., 2014).

However, studying examples can give learners an illusion of understanding (Baars et al., 2016; Baars, van Gog, de Bruin, & Paas, 2014; Renkl & Atkinson, 2002). An illusion of understanding is evident if students' predictions about their future test performance (judgments of learning, JoLs) are higher than their actual test performance (overconfidence; Thiede, Anderson, & Therriault, 2003). Illusions of understanding can be a result of a foresight bias (Koriat & Bjork, 2005), which occurs when predictions about one's future test performance with regard to certain material are made in the presence of that material. If students, for instance, are asked to make a JoL in the presence or immediately after studying a worked example, they might interpret their current processing as learning even though the current processing is based on the worked example that will not be available during a later test. Thus, learners may overestimate their future test performance. Illusions of understanding can have detrimental effects on learning outcomes, since they may lead learners to terminate studying too early (Dunlosky & Rawson, 2012). During schema acquisition, for example, overconfident learners might terminate studying before a schema is constructed or before all relevant elements of a schema have been encoded and incorporated. Thus, overconfidence might prevent or impair the acquisition of a problem-solving schema through inaccurate regulation processes. Illusions of understanding might be even more likely to occur when using video modeling examples to convey scientific reasoning skills. Dynamic visualizations like videos are commonly associated with entertainment. Therefore, students may underestimate the effort necessary to understand what is being conveyed through a dynamic visualization (underwhelming effect; Lowe, 2004).

Thus, both approaches – inquiry learning and example-based learning – have advantages (authentic inquiry activities vs. helping learners build problem-solving schemata) and disadvantages (high cognitive load vs. illusions of understanding) for novice learners. This raises the question of whether there are benefits of combining these two approaches compared to learning from just one approach. Moreover, when combining examples and inquiry tasks, one needs to consider the sequence in which the two are presented.

1.3. Sequencing learning activities

The question of how to sequence examples and inquiry tasks pertains to the more general question of how to sequence direct instruction and problem-solving activities. Research regarding this question has resulted in mixed evidence.

On the one hand, there is research speaking in favor of presenting instruction (such as examples) before problems (such as inquiry tasks). For instance, two studies have investigated the effectiveness of examples only, examples followed by tasks (example-task pairs) and tasks followed by examples (task-example pairs) compared with tasks only (Leppink, Paas, van Gog, van der Vleuten, & van Merriënboer, 2014; van Gog, Kester, & Paas, 2011). Both studies found an advantage for presenting examples first. Van Gog et al. (2011) found that secondary education students (age $M = 16.22$) who learned to troubleshoot electrical circuits via example-task pairs or examples only indicated lower cognitive load and showed better learning outcomes (better problem-solving skills) than students who learned with task-example pairs or tasks only. Moreover, students who learned with example-task pairs did not differ from students who learned with examples only. Similarly, students who learned with task-example pairs did not differ from students who learned with tasks only. Leppink et al. (2014) replicated the advantage of studying an example over solving a task first in a different domain (application of Bayes' theorem) and with an older age group (university freshman). Thus, research on worked examples speaks in favor of presenting an example first followed by either a task or another example.

Moreover, several studies on inquiry learning underscore that presenting instruction before inquiry has a positive effect on learning outcomes (Barzilai & Blau, 2014; Lazonder, Hagemans, & de Jong, 2010; Wecker et al., 2013). Barzilai and Blau (2014), for example, compared the effectiveness of providing a scaffold including examples before or after an inquiry activity to an inquiry activity without scaffolds. Results showed that learners who studied the scaffold before the inquiry exhibited higher problem-solving performance in a posttest than learners who either studied scaffolds after the inquiry or not at all (Barzilai & Blau, 2014). Taken together, research on worked examples and on instruction and inquiry suggest to provide instruction (e.g., examples) before problems (e.g., inquiry tasks).

However, there is also research speaking in favor of presenting problems before examples. Problem-example pairs might enable students to recognize deficiencies in their own performance, which might direct their attention to those aspects during studying the