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

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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
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 in enhancing learning and transfer (Wecker et al., 2013). 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, and task pairs (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
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