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Acquisition of troubleshooting skills in a computer simulation: Worked example vs. conventional problem solving instructional strategies

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Abstract

In a computer-based simulation of a chemical processing plant, the differential effects of three instructional strategies for learning how to troubleshoot the plant's malfunctions were investigated. In an experiment concerning learners' transfer performance and mental effort, the simulation presented the three strategies to three groups of learners and measured their performance on the transfer tasks. In this experiment, conventional problem solving was contrasted with two worked example strategies. The results indicated a significant difference between practicing problem solving and using worked examples. Learners who practiced problem solving in an interactive simulation outperformed the learners who studied computer-based worked examples. They also invested lower mental effort in transfer tasks. When accounting for the difference in the learners' domain knowledge, the strategies were not significantly different among the more experienced learners. For the less experienced learners, those who practiced problem solving significantly outperformed their worked example counterparts. Among all participants and also among less experienced learners the problem solving group invested significantly lower mental effort in the performance of transfer tasks. Based on the results of this study, the authors recommend the use of the conventional problem solving strategy with or without worked examples for learning complex skills.

Keywords: Simulation-based training; Computer-based training; Worked examples; Troubleshooting; Problem solving; Practice

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1. Acquisition of troubleshooting skills in a computer simulation: worked examples vs. conventional problem solving instructional strategies

Cognition occurs in two contexts, internal and external. The internal context involves the preexisting knowledge that a person brings to tasks. The external context involves the physical or social environment that, together with the internal context, constitutes a framework in which cognition takes place (Ceci, Rosenblum, & DeBruyn, 1998). This framework provides the "cognitive apprenticeship" environment for practicing learning tasks in which learners can make their "thinking visible" (Brown, Collins, & Duguid, 1989; Collins, Brown, & Holum, 1991). A similar argument is the basis of Piaget's (1966) learning theory that describes the interaction of a learner's existing schema, the internal context, with new information, the external context, by the process of *accommodation*. This process results in resolving dissonance between new information and the existing schema, which brings about learning (*equilibration*).

In a complex learning environment, such as troubleshooting malfunctions of a chemical processing plant, the difficulty of the learning tasks stems from the complexity of *integrating* knowledge, skills, and attitudes, *coordinating* qualitatively different constituent skills, and using schema-based processes in solving a problem (Van Merriënboer, Clark, & de Croock, 2002). Obviously, providing a real context for learners to practice these complex activities would not always be available or affordable. A computer simulation that offers the learners the opportunity for this integration and coordination provides the external context highly similar to a real-world framework. Given this argument, we programmed three instructional strategies in a computer simulation to provide learners with an authentic experience and investigate the impact of these strategies on learners' performance.

Conventional problem solving is one instructional strategy for acquisition and transfer of skills in a complex learning environment. Using this strategy, learners solve whole-task problems for the purpose of preparing to transfer their skills to a different problem situation (Van Merriënboer, 1997). However, the strategy has been criticized by scholars interested in the relationship of cognitive load and instruction.

Kalyuga, Chandler, Tuovinen, and Sweller (2001) argue that the conventional problem solving strategy can inhibit construction and automation of schemas for novice learners, and only benefits learners who have domain experience and thus existing schemas in that domain. According to Kalyuga, et al., novice learners rely on a means-ends strategy that imposes a heavy cognitive load when solving problems. Learners must "simultaneously consider the current problem state, the goal state, the differences between the current and goal states, the relevant operators and ... any sub-goals that have been established" (p. 579).

Another instructional strategy recommended for learning to solve complex problems is the use of worked examples (e.g., Kalyuga et al., 2001; Van Gog, Paas, & van Merrriënboer, 2004), a strategy somewhat similar to direct instruction. Van Merriënboer et al. (2002), Van Gog et al. (2004) identified "process-oriented" and "product-oriented" as two types of worked examples. Product-oriented worked examples describe the procedures involved in solving a problem by providing the learner with an initial state, a goal state, and a set of solution steps. Process-oriented worked examples, on the other hand, explain not only *how* to solve a given problem but also *why* the operations are employed.

The worked example strategy has been found to be more effective than conventional problem solving for enhancing learner performance (Atkinson, Derry, Renkl, & Wor-