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Reflective learning with complex problems in a visualization-based learning environment with expert support

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ABSTRACT

Effective learning through problem solving is difficult to realize as problem solving often involves complex processes that are inaccessible to novices. It is important to make the complex process visible to novices and provide them with necessary support throughout the tasks. This study proposes a computer-based learning environment that allows learners to capture their problem-solving process in a visual format for effective thinking and reflection. Moreover, expert support is incorporated to improve self-reflection by allowing learners to identify the difference between their performance and that of the expert. This study adopted a pretest-posttest control group design. The experimental group used the visualization-based learning environment involving expert support, while the control group used the visualization-based learning environment without expert support. Forth-five senior year medical students completed the study with five diagnostic problem-solving tasks in four weeks. The results showed that the inclusion of expert support made the visualization-based reflective learning environment more effective in improving learners' problem-solving performance, supporting their construction of knowledge from problem-solving tasks, and improving their confidence and satisfaction with the learning experience.

1. Introduction

Learning through problem-solving is a constructivist educational approach that situates learning in problem-solving contexts (Jonassen, 1997). It aims to help learners to develop critical thinking and problem-solving skills as well as consolidate and extend their subject knowledge. Learning through problem-solving is supported by situated learning theories, which claim that learning and cognition are fundamentally situated and therefore, learning is a process occurring in contexts where knowledge is created and applied (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Learning through problem solving is also supported by experiential learning theory (Dewey, 1938), which emphasizes that knowledge is created by engaging in and reflecting on experience, so called "learning by doing." Further, problem-solving experience is recognized as an integral part of expertise development (Ericsson, 2008; Schmidt, Norman, & Boshuizen, 1990). Finally, learning through problem-solving is closely related to problem-based learning, where students learn about a subject through the experience of solving open-ended problems (Hmelo-Silver, 2004).

Problem solving has received wide attention in educational practice, especially in complex and ill-structured domains such as medical education and scientific inquiry. Problem-oriented experience has been found to be effective in developing critical thinking, communication, and problem-solving skills and improving subject knowledge (Gijbels, Dochy, Van den Bossche, & Segers, 2005; Hmelo-Silver, 2004). Given the constraints of classroom settings in supporting learning with real-world problems and authentic tasks, technology-supported learning environments (e.g., virtual environments, computer-based simulations, and web-based applications) have increasingly been explored as a way to support learning in problem-solving contexts (e.g., Linn, 2000; Lajoie,

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Lavigne, Guerrera, & Munsie, 2001; Chau et al., 2013; Wong, Ma, Yang, Yiu, & Yang, 2017).

Challenges to learning in problem-solving contexts. However, effective learning through problem solving is difficult to realize in both classroom and computer-based settings. Solving a real-world problem often involves a sophisticated process of understanding the problem, linking abstract knowledge to problem information, and applying relevant methods and strategies to solve the problem. Learning in such contexts can pose heavy cognitive demand to learners (Kirschner, Sweller, & Clark, 2006), which instructors or experts often underestimate as for them, many of the requisite processes have become largely automatic or subconscious with experience. As a result of their limited capability to capture the complex problem-solving process, many learners tend to engage in surface experience and fail to achieve the desired learning outcomes.

Learning through problem solving has been widely adopted in medical education by way of problem-based learning curricula, case-based sessions, and internship programs. Several reviews of the literature have shown that problem-based learning improves students' reasoning and communication skills, fosters their ability to cope with uncertainty, and encourages self-directed learning (Albanese & Mitchell, 1993; Hartling, Spooner, Tjosvold, & Oswald, 2010; Koh, Khoo, Wong, & Koh, 2008; Neville, 2009). At the same time, however, researchers have reported inconclusive and inconsistent findings regarding the superiority of problem-based learning over conventional instruction, mainly in the systematic construction of subject-matter knowledge and the development of an efficient reasoning process. A major concern is that completing a problem-solving task, such as clinical diagnosis, involves a complex cognitive processes of search for problem information about multiple aspects, integrating the problem information with subject-matter knowledge, and reasoning with intertwined variables (Delany & Golding, 2014; Wang, Wu, Kinshuk, Chen, & Spector, 2013). Many students have inadequate reasoning ability to accomplish problem-solving tasks.

Supporting learning with complex problems. To facilitate learning in complex situations, different types of support have been employed in educational practice. Direct guidance or instruction focuses on providing learners with relevant information or methods to accomplish learning tasks. Scaffolding or indirect guidance supports learning by the use of prompts, hints, and scripts to direct learners' attention towards important issues (e.g., what to do next) during the task, or by decomposing a complex task into a set of main actions or key questions (Hmelo-Silver, Duncan, & Chinn, 2007; Kollar, Fischer, & Slotta, 2007; Reiser, 2004). Providing support to learners in complex situations aligns with the cognitive apprenticeship model (Collins, Brown, & Holum, 1991), which maintains that carrying out a complex task usually involves implicit processes; it is critical to make such processes visible for novices to observe and practice, and to provide them with necessary help.

Making thinking visible for deeper learning. Recent research highlights the importance of making thinking visible in complex problem or task situations for deeper learning (Wang, Kirschner, & Bridges, 2016). Deeper learning is characterized by a high level of engagement in learning, driven by intrinsic motivation and, more importantly, supported by relevant learning approaches that help learners persist through challenges and setbacks to achieve a high level of understanding and performance (Wang, Derry, & Ge, 2017). Research on deeper learning has focused on what is called deep approaches to learning (Chin & Brown, 2000; Entwistle, 2000) and has concentrated on multiple issues involving externalizing the tacit aspects of complex tasks for effective thinking, action, and reflection; relating new ideas to prior knowledge and experience for effective construction of knowledge from practice; and combining discrete pieces of knowledge into a coherent whole (Wang et al., 2017).

Deep approaches to learning appear more likely to occur in association with reflection. The connection between reflection and deeper learning corresponds with the theoretical position of Moon (1999) that the iterative process involved in reflection may be the key to moving from a deep to a surface approach to learning. As noted above, learning through problem-solving is supported by experiential learning theory, which claims that the outcomes of experiential learning depend not only on experience but, more importantly, on reflection on experience (Moon, 1999; Schön, 1983). Reflection, the process of making sense of experience by thinking about what one has been doing, identifying gaps and updating knowledge and skills, is crucial to experiential learning and continuing development, especially in complex or ill-structured domains such as medical education (Mann, Gordon, & MacLeod, 2009).

Externalization of complex cognitive processes in graphic, diagrammatic and pictorial forms is found to play a critical role in fostering in-depth thinking and reflection and improving learning outcomes in inquiry and problem-solving contexts Chen, Wang, Dede, & Grotzer, 2017; Gijlers & de Jong, 2013; Janssen, Erkens, Kirschner, & Kanselaar, 2010; Linn, 2000; Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008; Wu, Wang, Grotzer, Liu, & Johnson, 2016). Making complex thinking or cognition visible can be linked with model-based learning and instruction, that is, the use of mental models to uncover cognitive processes and architectures to gain insights into the nature of complex problem solving (Greca & Moreira, 2000; Seel, 2003). Other related work refers to model-based assessment, i.e., assessing people's thinking about a problem situation by asking them to represent their understanding in a mental model with the support of computer-based tools (Pirnay-Dummer, Ifenthaler, & Spector, 2010).

Expertise development. Nevertheless, given their limited practical experience and the complexity of real-world problems, many learners have difficulties capturing the essential aspects of the problem-solving experience for adequate reflection and the development of expert-like performance. In addition to enabling learners to capture their problem-solving process for self-reflection, there is a need to explore how learners' performance can be further improved by extending self-directed reflective learning towards expert-supported reflective learning for expertise development (Mann et al., 2009). Research on expertise development has revealed that desired learning outcomes in problem-solving contexts cannot be achieved through a mere accumulation of experience but require systematic and deliberate effort with expert support (Ericsson, 2008; Jarodzka, Scheiter, Gerjets, & van Gog, 2010). Williams et al.'s (2011) study on clinical reasoning education reported that students did not make expected rapid progress in problem-solving or reasoning performance after intensive clinical experience in their senior years of medical school. Therefore, it is important to make complex cognitive processes visible to novices and provide them with necessary support for complex problem-solving.

The present study. This study proposes a visualization-based learning environment (VLE) that allows learners to capture their problem-solving process in a visual format for effective thinking and self-reflection. Moreover, expert support is incorporated in the system to enhance reflective learning by allowing learners to identify the difference between their performance and that of the expert. An empirical study was conducted with medical students to determine the effects of the proposed approach by comparing it to a similar learning environment with visualization-based facilities but