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The Design Principles of the Worked Examples

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Abstract: Problem-based learning strategy has been frequently adopted to develop students' problem-solving ability. Despite the fact that its effects have been reasonably argued and empirically tested, its associated learning task may overload the learners, especially the novice. This paper, grounded on the cognitive load theory, argued the potentials of introducing the worked examples into problem-based learning activity. The purpose of this study is to explore the design principles of worked examples and test its effects. The geometric logic problem type was chosen as the main problem for participants to explore during the problem-based learning activity. A series of geometric logic problems was developed and tested in a pilot study to ensure its quality. Furthermore, worked examples and practice session were developed based on the principles suggested in the literature. A web-based learning system was created to engage participants in observing the logical problems, watching the examples and practicing solving the given problems. A pre-and-post experimental design was adopted to test the effect of worked-examples. Twenty-eight university students, matriculated in information-related programs, were recruited. The finding supported the positive effect of the worked examples on enhancing students' logic problem solving performance.

Keywords: Geometric logic problem-solving, worked examples, problem-based learning

1. Introduction

Problem-based learning strategy has been extensively employed in many domains to enhance students' learning, thinking and problem-solving skills (Barrows, 1997; Gallagher, Sher, Stepien and Workman, 1995; Tiwari, Lai, So and Yuen, 2006). Problem-based learning starts learning with a real-world problem (Hmelo and Evensen, 2000) and encourages students' active exploration of the given problems and knowledge construction. During the process, students practice synthesizing learned concepts, constructing their schema as well as the problem-solving process. This process is cognitively demanding, which requires students to devote cognitive efforts to interpreting the problems, identifying domain knowledge that is relevant to the problems, generating, testing and evaluating possible solutions. The novice with less domain knowledge or problem-solving experience may be overloaded. Therefore, timely guidance provided to them may help them sustain their constantly cognitive engagement.

Prior studies have suggested incorporation of worked examples as a guidance into problem-based learning (e.g. Ayres and Paas, 2009; Kirschner, Paas, Kirschner and Janssen, 2010; Renkl, 1997; Sweller, van Merriënboer and Paas, 1998; van Merriënboer and Sweller, 2005). Providing worked examples can make it easier for students to associate the domain knowledge with the problem-solving process and grasp the problem solving skill as well. Therefore, this study explored the design principles of the worked example and tested the effect of worked examples on university students' problem-solving performance under the problem-based learning context.

2. Literature Review

2.1 Theoretical Foundation: Cognitive Load Theory

Cognitive load theory suggests that learning tasks impose cognitive loads on students. If the cognitive efforts demanded by a task exceed learners' cognitive capacity, meaningful learning will not occur (Sweller, 2010; Sweller et al., 1998). The cognitive load imposed by a learning task is determined by the complexity of the learning task and students' cognitive capabilities and knowledge. Specifically, the complexity of a task is estimated as the amounts of information elements presented and the complexity of the knowledge structure in which those information elements are embedded (Sweller, 2010). In order to correctly interpret and process a learning task, learners not only need to understand the concepts represented in the information elements, but also need to think through the interrelationships among those elements. Meanwhile, learners' cognitive capability and domain knowledge determine whether they could effectively and efficiently execute relevant schema to interpret and process the facing task.

The problem-based learning task itself might demand students' intrinsic cognitive efforts to explore the knowledge elements embedded in the given problem and task. However, students with less knowledge or lower cognitive capabilities might devote their attentions and efforts both to relevant and irrelevant information, which might exceed their limited cognitive capacity and thus, diminish the positive learning effect of problem-based learning (Sweller, 2010; Sweller et al., 1998). Therefore, it is essential to design appropriate worked examples not only to reduce the extraneous cognitive load imposed by problem-based learning, but also to engage students in making use of problem-based learning to manage their limited cognitive capacity to construct their schema (Ayres and Paas, 2009; Kirschner et al., 2010; Paas and van Gog, 2006).

2.2 Worked Examples

As suggested by cognitive load theorists, a well-design worked example could direct students' attention to relevant information and necessary reasoning process, decreasing cognitive efforts being devoted to reading the irrelevant information and trying-out the strategies (Renkl, Mandl and Gruber, 1996). Furthermore, it helps them to concentrate on schema activation, observing the problem-solving strategies and process presented in the examples, thus leading to construction of their own schema for solving similar problems (Atkinson, Derry, Renkl and Wortham, 2000; Paas and van Merriënboer, 1994; van Gog, Paas and van Merriënboer, 2004).

The essential components of the worked examples were summarized from the literature and discussed in a number of publications (Baghaei, Mitrovic and Irwin, 2007; Hmelo and Evensen, 2000; Moreno, 2006; Renkl, 1997; van Gog, Paas and van Merriënboer, 2006). First, the example should contain the problem representation, identifying the information that is critical for problem analysis. Second, the example should demonstrate experts' reasoning process and plan with explicit explanation of critical reasoning points. Third, the example should present the problem solving steps by explaining the concepts or strategies utilized and the rationale. Fourth, the example should stimulate students in thinking of causal effects and underlying principles. Fifth, students should be able to monitor their learning during interacting with the examples. That is, they could determine the amount of examples to observe and their learning pace. Last, students should be given the opportunity to practice problem-solving strategies learned from the examples.

3. Research Method

3.1 Research Design

Twenty eight university students majoring in information-related programs were recruited for the pre- and post-test experimental study. The geometric logic problem type was chosen as the main problem for participants to explore during the PBL activities. A series of geometric logic problems was developed and tested in a pilot study to ensure its quality. Furthermore, a series of worked examples and practice session were embedded in the web-based learning system, named Collaborative Exemplified Problem Reasoning System (CEPRS). The system allowed participants not only to interact with the given logic problems by watching the problem scenarios, trying out solutions, gaining instant feedback, but also to watch the worked examples. Furthermore, participants' solution paths and steps and time spent on watching each worked example and practice were recorded.

A training session was delivered at the beginning to ensure that the participants possessed the fundamental computer skills required for interacting with the given logic problems within the adopted learning system. After training, each participant accomplished the pre-test. Participants then worked with the system to conduct the learning task, which includes 5 example sessions and 5 practice sessions. The participants could watch the examples on their own pace before proceeding to practice applying the learned strategies to solve the logic problems. At the end, each participant accomplished the post-test.

3.2 Variables and Instruments

Five worked examples were designed and presented. First, in regard with the components of the examples, the first example focused on representing the problems by revealing important information and explaining how such information might influence ways to approach the problems. The rest of the four examples represented problems with different level of difficulty as well as introduced a strategy to guide students to reason through the problem and generate possible solutions. Second, all the examples demonstrated how the introduced strategy was utilized. Participants could observe each step of how a problem is solved and informed of the rationale for taking the step. Third, a practice session was presented after an example was demonstrated. The practice session, containing two problems with equivalent difficulty as those presented in the example. The practice session allowed participants to apply the learned strategy. Instant feedback was also provided to the participants so that they are able to monitor their own problem-solving process. Fourth, participants were granted the freedom to determine their learning pace. On one hand, they could use the control panel in the system to control their process of watching individual examples. On the other hand, they could determine the timing to switch between the example sessions and the practice sessions.

The dependent variable, which refers to students' logic problem-solving performance, was assessed by the correctness of solving the given 10 logic problems within 25 minutes. Both of the pre-test and posttest included 10 logic problems. To avoid the effects of practicing the test items, a parallel test was created. That is, the problem scenarios, goals, requirement and limitation adopted in the post-test are different from those adopted in the pre-test. Furthermore, a pilot test, recruiting 30 subjects, was conducted prior the actual study to ensure the quality of the tests. The difficulty of the items reported in the pilot study ranged from 0.36 to 0.86 and the averaged discriminability was 0.69, which indicated an acceptable quality of the instrument. The average difficulty and discriminability reported in the actual study was 0.45 and 0.55, respectively.

4. Results and Conclusions

The descriptive statistics of the variables are listed in Table 1. It can be seen that the post-test score (Mean=4.43) is higher than the pre-test score (Mean =7.71).

Table 1. Descriptive statistics

Variable	No.	Pre-test		Post-test	
		Mean	SD	Mean	SD
Worked Examples	28	4.43	2.13	7.71	1.82

The paired t-test result showed that the post test scores of the students working in the group of watching examples followed by practice were significantly higher than the pretest scores. (t =8.87, p < .01). In other words, the participants' logic problem performance was significantly enhanced after being engaged in watching the worked examples.

This study contributed to the literature on problem-based learning. First, this study explored the design principles from the cognitive load theory perspectives and developed a series of the worked examples based on the principles. Second, this study validated the effect of the worked examples on enhancing students' logical problem-solving performance. As this study adopted the quantitative approach, experimental design, to investigate the effect of the worked examples on participants' growth in problem-solving performance, future research is suggested to take a qualitative approach to explore how subjects interact with the given worked examples to influence their subsequent problem-solving activities. Furthermore, the geometric logic problem-solving was adopted as the core problem type in this study. Different problem types have different characteristics in problems representation and engage students in employing different problem reasoning and solving strategies. Therefore, to extend the design principles into developing worked examples for different problem types and empirically validate the effects would be important and highly recommended.

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