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Worked Examples as Application of Analogical Reasoning in Intelligent Tutoring and their Effects on SQL Competencies

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The acquisition of problem-solving skills such as solving mathematical equations or programming demand a substantial number of cognitive schemata. Problem-based learning has been found to improve general problem-solving strategies and critical thinking and outperform lecture-based environments (Yew & Goh, 2016). Presenting worked examples (WEs) facilitates the acquisition of required knowledge (Sweller & Cooper, 1985). WEs display all required steps to solve the problem and this insight can be transferred to the current problem (VanLehn, 1998). The mapping process can be viewed as analogical reasoning and requires isomorphic WEs with the same underlying structure as the current problem (Gick & Holyoak, 1983). Learning from analogies allows for building problem-solving schemata and increases knowledge by schema abstraction (Gentner & Maravilla, 2018). Analogical comparison is assumed to be more effective for far transfer problem solving than near transfer compared to methods such as self-explaining (Nokes-Malach et al., 2013). An approach for an automatic generation of isomorphic examples was proposed by Zeller & Schmid (2016). There, the generated isomorphic example was constrained such that it highlights identified misconceptions. In the domain of programming, examples are especially effective to support the acquisition of more general program schemes (Pirolli & Anderson, 1985).

Najar et al. (2015) incorporated WEs in an existing intelligent tutoring system (ITS) called SQL-Tutor (Mitrovic & Ohlsson, 1999), and found that novices investigated only WEs, while advanced students also focused on additional information such as database schema. SQL-Tutor employs Constraint-Based Modeling, an approach where the domain knowledge is formulated as a set of constraints, which helps identify incorrect or incomplete knowledge if the student violates these constraints (Mitrovic & Ohlsson, 1999). The system allows individual feedback on several levels of increasing degree of assistance. To ensure structural similarity independent of the complexity of posed SQL problems, WEs are created according to problem templates with identical underlying structures but different surface structures (Mathews & Mitrovic, 2007). The use and effectiveness of WEs in ITSs depend on the learner's prior knowledge (Najar et al., 2015). Additionally, it is postulated that motivation and metacognitive strategies play a role in the proper use of feedback within an ITS (Hull & Du Boulay, 2015). Providing examples can enhance students' motivation to interact with the problem domain more thoroughly (Narciss & Huth, 2006). High self-efficacy expectations, i.e. the perceived competence in performing a task, can determine further self-regulatory learning strategies and seem to strongly mediate the use of provided materials (Hull & Du Boulay, 2015). Apart from observable performance measures, ways to increase positively correlated subjective measures such as self-efficacy for programming tasks should be explored further.

We are currently conducting an experiment (July 2022) to investigate the effects of WEs as an implementation of analogical reasoning on the perceived and measurable competency in a programming task. Students will be formulating SQL queries using SQL-Tutor (Mitrovic, 2003). We use pre/post-tests to determine students' conceptual and procedural knowledge of SQL, as well as self-efficacy expectations towards SQL skills before/after the study session. There are three groups of students. In the case of submitting an erroneous solution, the experimental group 1 (EG1) students receive an isomorphic WE from the same database, while the experimental group 2 (EG2) students receive an isomorphic WE from a different database. This distinction between databases aims to test previous findings on the hypothesis that analogical comparison works better on far transfer problems, so we expect higher scores for EG2. The control group students receive the full solution instead of a WE. After receiving WEs or the full solution, the students will have one more attempt to solve the problem or copy the correct response accordingly. We hypothesize that the analogical mapping of insights of the WEs to the target problem encourages a deeper cognitive analysis and should have positive effects on performance. We also hypothesize that WEs shift the focus from pointing out

students' single errors to viewing the ITS support as an additional learning opportunity, and so WEs should have a positive effect on students' self-efficacy expectations.

Keywords: Intelligent Tutoring Systems, SQL-Tutor, Analogical Reasoning, Worked Examples

Problem		Worked Example	
List the numbers, names and ages of all movie stars who are deceased.		List the first and last name and their response rate-time-ratio of all hosts that are verified.	
Solution			
SELECT	number, lname, fname, died-born	SELECT	number, lname, fname, response_rate/response_time
FROM	star	FROM	host
WHERE	died IS NOT NULL	WHERE	verification IS NOT NULL

Figure 1. Example of SQL problem with solution (left) and WE from a different database (right).

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