The Contributions of Studying Examples and Solving Problems to Skill Acquisition†

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Abstract:

There is little doubt that examples play a major role in acquiring a new skill. How examples improve learning, however, is subject to some debate. Recently, two different classes of theories have been proposed to explain why examples are such an effective manner of learning. *Example Generalization* models suggest that problem solving rules are acquired while studying examples. *Knowledge Compilation* models, on the other hand, suggest that examples are useful because they guide future problem solving, where the necessary rules are created. Consistent with knowledge compilation models, we found that separating target problems from source examples hindered learning because the source examples could not be remembered to guide problem solving. We also found that if sources are not accessible or remembered during problem solving, learning occurs best when the sources are problems to be solved, rather than examples. Taken together, these results provide strong support for the knowledge compilation view: in order for an example to be most effective, the knowledge gained from the example must be applied to solving a new problem.

Introduction

Typical instruction in problem solving domains includes expository text, annotated examples, and problems to solve. Examples play a critical role in guiding the learning process. Students rely heavily on examples in instructional text, focusing more on adapting the method used in an annotated example than on the verbal explanations of a procedure in instructional text (LeFevre & Dixon, 1986; VanLehn, 1986). Two different sources of the benefits of examples have been proposed, however — learning while studying the examples themselves (Sweller & Cooper, 1985; VanLehn, Jones, & Chi, 1992), and later analogical use of the examples during problem solving (Anderson, 1987; Pirolli, 1991; VanLehn et al., 1992).

Sweller and Cooper (1985) claim that students can effectively learn procedures by studying annotated examples with minimal instructional text, and this learning can be more effective than unguided problem solving. Sweller (1988) further argued that cognitive load can be reduced and problem solving schemas can be built more easily by studying examples. Indeed, if a problem solving episode contains extensive search and error recovery, students have difficulty learning from the experience (Lewis & Anderson, 1985). The importance of learning from examples is also suggested by evidence that the way students study examples greatly affects subsequent problem solving performance — the degree to which students explain instructional examples to themselves determines how much is learned from them (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Furthermore, problem solving rules can be acquired as a result of this self-explanation process (VanLehn et al., 1992). These *example generalization* models suggest that problem solving knowledge is critically acquired while studying examples. In fact, Sweller and Cooper (1985) argued that unguided problem solving is a poor learning device and should be used only as motivation for students to attend to the examples.

What knowledge is gained by solving problems that could not be acquired by studying examples? In *knowledge compilation* models, construction of problem solving knowledge critically relies on *applying* knowledge to solve problems (Anderson, 1982, 1987). This view claims that studying an example produces a declarative representation that can guide search and thereby facilitate constructing a solution on problems similar to the example. A critical tenet of this view is that problem solving is required to form problem solving rules (Anderson & Thompson,

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1989; Pirolli, 1991). Similarly, in VanLehn et al.'s (1992) CASCADE model, students' explanations of examples are later used analogically to facilitate solving similar problems, leading to more effective rule construction.

In summary, a critical part of problem solving knowledge appears to be acquired when students study examples (Sweller & Cooper, 1985; VanLehn et al., 1992). However, in knowledge compilation models, the process of studying examples itself can only result in declarative knowledge, and students must draw upon this knowledge to solve problems in order to acquire problem solving skill (Anderson, 1987; Pirolli, 1991). The present experiment examines the contributions of studying examples and problem solving to the acquisition of problem solving skill in a domain.

If the benefit of studying examples derives at least in part from applying an example to help solve a later problem, then this benefit should be reduced if the subjects' ability to access information from the example is hampered. In all of Sweller's experiments demonstrating the effectiveness of examples for learning, source examples were immediately followed by relevant target problems drawing on the knowledge exemplified in the prior example. In contrast, if the source examples were separated from later relevant target problems, then subjects would have to select which prior example is applicable, and may have to rely on only partially complete memories of the examples. In knowledge compilation models, learning from examples requires using them to guide later problem solving, hence separating target problems from relevant examples should interfere with learning. On the other hand, if students acquire sufficient problem solving skill by studying examples, as argued by example generalization models (e.g., Sweller & Cooper, 1985), then separating the target problem from the source example should not affect later problem solving effectiveness or learning outcomes. The present experiment examines these hypotheses.

Experiment

We constructed source and target problems in a LISP programming curriculum that overlapped in the subskills necessary for their solution. We manipulated the *order* of problems (alternating or blocked sources and targets) and the *activity* on the sources (study examples or problems to solve). Subjects in the two "alternating" conditions saw each source (1a, 2a, etc.) immediately followed by the related target problem (1b, 2b, etc.), while subjects in the two "blocked" conditions were given all the sources followed by all the targets (see Table 1). Subjects in the two "example" conditions studied annotated examples as their source problems, while subjects in the two "solve" conditions solved their source problems. Subjects could not access previously seen examples or problems. Subjects in each condition solved the same target problems.

The two central predictions of knowledge compilation theories concern (1) the effect of separating example sources and targets, and (2) the effect of solving a block of sources rather than studying them as examples.

First, will separating example sources from targets to be solved hamper learning? According to the example generalization view, learning from examples occurs solely while subjects study the examples, so the sequence of examples and problems should not affect subjects' performance. Alternatively, if examples facilitate learning not only because of the elaborations subjects generate while studying them, but also when they are forced to draw on their mental representation of the example to guide later problem solving (Anderson & Thompson, 1989; Pirolli, 1991; VanLehn et al., 1992), then separating a source example from similar target problems should hamper learning, because selecting and remembering an example may be less successful. The comparison of the Alternating Example and Blocked Example groups evaluates this hypothesis.

A second test of whether the benefit of examples depends on their use during problem solving concerns the comparison between the two blocked conditions. In previous studies, Sweller and Cooper (1985) found that studying worked out examples led to better learning outcomes than solving the same problems. Their support for this assertion relied on interspersing source examples with target problems (intended to motivate subjects to attend to the examples). If the benefit of the examples depends in part on their use during problem solving, then the advantage of studying source examples relative to solving them should be reduced if the targets are not interspersed. Thus, if sources and targets are presented in a blocked format, knowledge compilation theories (e.g., Anderson, 1982; Pirolli, 1991) predict that the additional practice the solve condition receives may outweigh the guiding benefit of the examples, leading the Blocked Solve subjects to perform better than the Blocked Example subjects.

Finally, in the case where the sources should be accessible because they immediately precede targets,

Alternating Example	**Alternating Solve**	**Blocked Example**	**Blocked Solve**
Example 1a Solve 1b	Solve 1a Solve 1b	Example 1a Example 2a	Solve 1a Solve 2a
Example 2a Solve 2b	Solve 2a Solve 2b	Example 3a Example 4a	Solve 3a Solve 4a
⋮	⋮	⋮	⋮
Example 4a Solve 4b	Solve 4a Solve 4b	Solve 1b Solve 2b	Solve 1b Solve 2b
Example 5a Solve 5b	Solve 5a Solve 5b	Solve 3b Solve 4b	Solve 3b Solve 4b
⋮	⋮	⋮	⋮

Table 1: Tasks for each condition. A's are sources and B's are targets. Identical numbers are similar to each other.

the predictions of knowledge compilation theories are less clear. In this situation, is it better to study the source example or solve the source as a problem? Recall that Sweller and Cooper (1985) found a strong learning outcome advantage for studying source examples rather than solving them. Knowledge compilation models would also predict some advantage in studying the example, because the example can be used analogically to guide problem solving on the target (Anderson, 1982; Pirolli, 1991), and limiting search and error recovery facilitates rule formation (Lewis & Anderson, 1985). On the other hand, the solved sources may also serve, to some extent, as analogical sources to guide problem solving during the targets (Faries & Reiser, 1988), and provide extra practice to potentially tune and strengthen problem solving knowledge. The prediction of example generalization theories, however, are clear: Studying source examples should produce better learning outcomes than solving source problem.

The contrasting predictions are summarized in Table 2.

Method

The subjects were 40 undergraduate paid volunteers from Princeton University and other nearby colleges.[1] Ten subjects were assigned to each condition, approximately matched on Math SAT. All subjects had taken no more than one semester of computer programming and had no prior knowledge of LISP.

Apparatus and Materials: Subjects worked through two chapters of an introductory LISP textbook (Anderson, Corbett, & Reiser, 1987) using BATBook, an electronic book and problem solving environment (Faries & Reiser, 1988). Expository text, examples, and problems were all presented on BATBook. Subjects read the textbook displayed on the computer screen, and could search the text for any target word or phrase. The examples contained a problem statement, a program that solved the problem, and several sentences of explanation describing how the program satisfied the problem's constraints.

Subjects worked on assigned problems in BATBook's LISP window (consisting of a simple editor and LISP interpreter). Subjects could test their programs on their own data and submit answers they considered correct. BATBook accepted correct solutions, or briefly pointed out data for which the program produced an error or incorrect result. Subjects could give up after three incorrect attempts and see a correct answer. While studying worked out examples or working problems, subjects were free to search the expository text. However, they did not have access to prior examples or their prior solutions at any time. BATBook records all interactions, including time spent reading each page, searching, studying examples, and problem solving attempts.

Learning Session: Subjects were given a brief demonstration during Chapter 1 to familiarize them with the learning environment, including reading and searching the text and solving problems. Subjects then studied examples, solved problems, and read the

[1]Data from 3 potential subjects were not used because of computer crashes and data from 1 potential subject were not used because the subject took over 2 standard deviations longer than the next slowest subject.

Theory	*Predictions*	*Reason*
Rules Compiled while Solving Problems	Alternating Example better than Blocked Example	Examples must be used during problem solving; blocked examples are less accessible.
	Blocked Solve better than Blocked Example	Examples are poorly remembered. Blocked Example has less practice.
Skill Learned while Studying Examples	Alternating Example equal to Blocked Example	Learning occurs while studying examples. Equal number of examples.
	Blocked Example better than Blocked Solve	Learning occurs while studying examples, not solving problems; Solving problems motivates subjects to attend to examples.
	Alternating Example better than Alternating Solve	

Table 2: Predictions of Knowledge Compilation versus Example Generalization theories.

remaining text at their own pace. All subjects were given the same sequence of study examples and problems to solve in Chapter 1. Chapter 2 implemented the learning conditions shown in Table 1. There were six sources and six targets; subjects in the two solve conditions solved twelve problems and saw no examples, subjects in the two example conditions studied six examples and solved six problems.

Posttest: A posttest consisting of three near transfer problems followed the learning session. Subjects were free to test their programs in the LISP window, but unlike the learning session, they received no feedback when they submitted answers to the posttest problems.

Results and Discussion

We examined the time to study or solve source problems, the time required to solve target problems, the accuracy of first solutions to each target problem, and the accuracy of the submitted solutions to the posttest problems. We measured program accuracy by counting the minimum number of program components to be added, deleted, or replaced to render the program a correct solution.

Learning Session, Chapter 1: Students solved over 98% of the problems correctly in Chapter 1. As expected, there were no differences in overall time or solution attempts, all F's non–significant. These results suggest that subjects were appropriately matched in ability level between conditions, and reached equal levels of proficiency on the material prerequisite to the experimental manipulations in Chapter 2.

Does separating source examples from target problems hamper learning? Knowledge compilation theories argue that learning from studying examples requires applying information from the example to the problem to be solved, so separating target problems from the example sources should hinder learning. Thus, we expected the subjects who solved a target problem immediately after the source example (Alternating Example) to learn more than subjects who studied a block of source examples followed by a block of solving target problems (Blocked Example). As expected, subjects who solved problems interleaved with examples took less time on the target problems than subjects who studied a block of source examples and a block of target problems (see Figure 1), Tukey test, $p < .05$. The accuracy of first solution attempts did not differ for the Alternate Example condition and the Blocked Example conditions (85% vs. 78%), Tukey test, $p > .10$. The solution time advantage can not be attributed to differing levels of motivation to attend to the examples; subjects spent equal time studying examples, $F < 1$. The posttest results (Figure 2) were consistent with the learning session results. Subjects in the Alternating Example condition submitted more accurate solutions than subjects receiving blocked examples, Tukey test, $p < .05$.

Is solving sources better than studying examples if the examples are not accessible during subsequent problem solving? Our second test of the knowledge compilation view compares subjects who solved a block of source problems (Blocked Solve) to those who studied the same block of examples (Blocked Example). We expected the Blocked Solve subjects to exhibit superior problem solving and learning, since Blocked Example subjects may have difficulty drawing upon the examples to guide later problem solving. The additional opportunities to practice and tune problem solving rules would therefore outweigh the potential facilitating effects of guid-

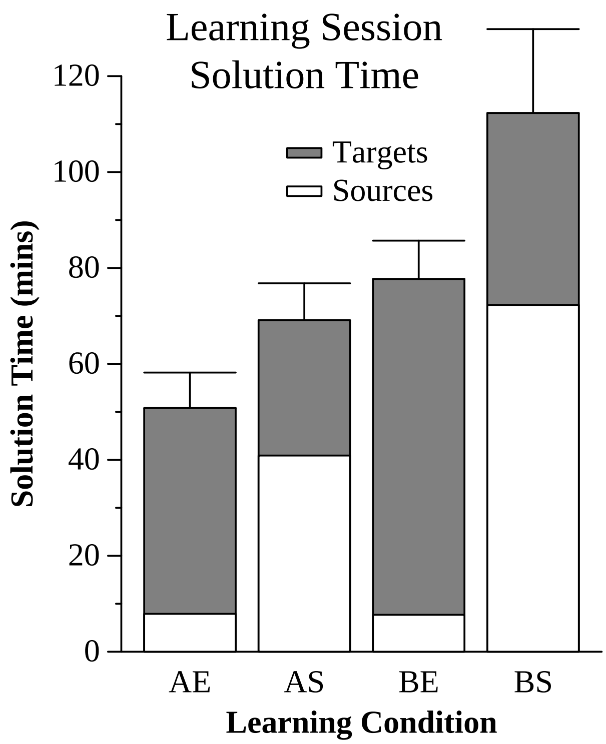

Figure 1: Time spent on Chapter 2 sources and problems. Error Bars are S.E.M.

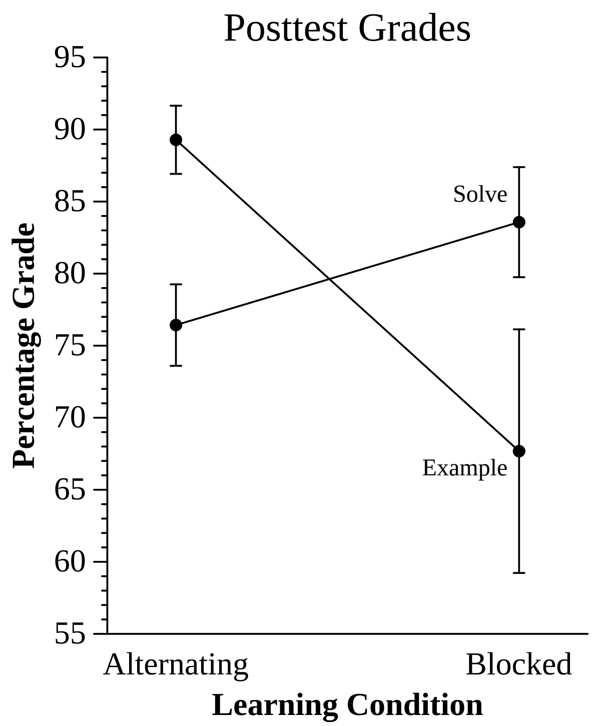

Figure 2: Grades on the Posttest.

ing examples. Consistent with this hypothesis, subjects in the Blocked Solve condition solved the target problems faster than subjects in the Blocked Example condition, $F(1,35) = 11.2$, $p < .01$. Again, there were no differences in accuracy of first solutions, $F(1,35) = 2.05, n.s.$ Furthermore, subjects in the Blocked Solve condition performed better on the posttest than subjects in the Blocked Example condition, $F(1,35) = 5.2$, $p < .05$.

Taken together, these two results provide strong support for the knowledge compilation view and against the extreme form of the example generalization view. These results suggest that source examples derive their benefit not only from the elaborations subjects form while studying them, but also when they access their memories of examples while solving later problems. If subjects are not able to recall a relevant example, the benefit of these elaborations is reduced. Subsequent problem solving appears to be required to derive the full benefit of studying examples.

Accessible sources: solving versus studying. When subjects solved a target problem immediately after studying or solving the source, they were presumably better able to recall the details of that problem. In this situation, the example or prior solution is presumably available to guide problem solving on the target problem. Here, there are conflicting factors predicted by knowledge compilation: solving the source creates more opportunities for practice, and solved sources may be able to be used analogically to guide problem solving on the targets. However, if the problems are difficult enough, then the subjects' own solutions may contain extensive search and error recovery, and hence may be difficult to use as analogical sources.

Here the results were somewhat puzzling. Subjects who studied examples interleaved with problems took somewhat longer to solve the target problems than the subjects who solved all the problems in an interleaved fashion, though this difference is not reliable, $F(1,35) = 2.68$, $p < .12$. The accuracy of the first solutions for Alternating Example and Alternating Solve subjects also did not differ (85% vs. 87%), $F(1,35) < 1$. However, subjects in the Alternating Example condition performed better on the posttest than did subjects in the Alternating Solve condition, $F(1,35) = 4.3$, $p < .05$. Evidently, the examples helped Alternating Example subjects learn more, but did not enable them to solve the targets more quickly.

The comparison between the two alternating conditions is intriguing. Subjects solving problems in an interleaved fashion solved the target problems faster than subjects who studied examples in an interleaved fashion, though there was no difference in grades during acquisition. Even though subjects who studied examples took somewhat longer, their time was well spent: they performed better than all other conditions on the posttest. Our explanation for this result is that when subjects study the example, they encode it into declarative memory. If they have access to this information when they solve a problem (the Alternating Example subjects), they use the example to build rules that are applicable for both the example and the problem. Subjects who have reduced access to the example (the Blocked Example subjects) flounder when solving the target problem, which leads to mediocre rule–formation. Perhaps subjects who solve both sources and targets (the Alternating Solve and Blocked Solve conditions) build one set of rules for the source, and another related set of rules for the target problem, resulting in a greater number of rules that are less efficient. Furthermore, they may have more practice with other aspects of the task itself that do not affect posttest performance, such as understanding and responding to the system's debugging feedback. Because their set of rules is not as general as the subjects in the alternating example condition, they do not perform as well on the posttest. This analogical process to build general rules may not have been as fast as solving both source and target, but the process appears to have resulted in better rule acquisition.

In summary, studying examples is clearly a very effective method to improve learning. In order for an example to be most effective, however, the knowledge gained from the example must be applied to solving a new problem. The most efficient way to present material to acquire a skill is to present an example, and then a similar problem immediately following. We hypothesize that this presentation method allows subjects to construct rules that are general enough to work for both the example and the rule. Although the extra practice solving sources may speed target problem solving, apparently more effective problem solving rules are formed when target problem solving can be guided by an accessible source example.

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