Bridging Principles and Examples through Analogy and Explanation

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Abstract: Previous research in cognitive science has shown that analogical comparison and self-explanation are two powerful learning activities that can improve conceptual learning in laboratory settings. The current work examines whether these results generalize to students learning physics in a classroom setting. Students were randomly assigned to one of three worked example learning conditions (reading, self-explanation, or analogical comparison) and then took a test assessing conceptual understanding and problem solving transfer. Students in the self-explanation and analogy conditions showed improved conceptual understanding compared to students in the more traditional worked example condition.

Introduction

What learning activities lead to a deep understanding of new concepts and support problem solving transfer? One approach to addressing this question is to examine what knowledge comprises 'expert understanding' and then design learning environments to help novices construct that knowledge. Research on expertise suggests that a key aspect of expert knowledge is understanding how the domain principles are instantiated in the problem features (Chi, Feltovich, & Glaser, 1981). The purpose of the current work was to design learning activities based on cognitive science principles to help students acquire this knowledge and improve their conceptual understanding.

Two learning paths that have been hypothesized to facilitate deep learning are self-explanation and analogical comparison. Self-explanation has been shown to facilitate both procedural and conceptual learning and transfer of that knowledge to new contexts (Chi, 2000). Of particular interest to the current work are some promising results from the Chi, Bassok, Lewis, Reimann, & Glaser (1989) laboratory study showing that good learners were more likely than poor learners to generate inferences relating worked examples to the principles and concepts of the problem. This result suggests that *prompting* students to self-explain the relations between principles and worked examples will further facilitate learning and conceptual understanding. Prior laboratory work has also shown that analogical comparison can facilitate schema abstraction and transfer (e.g., Gentner, Lowenstein, & Thompson, 2003; see Gentner, Holyoak, & Kokinov, 2001 for a general overview). However, this work has not examined how learning from problem comparison impacts understanding of how abstract principles relate to the problem features. The current work examines how self-explanation and analogical comparison may help bridge students' learning of the relations between principles and examples.

Experiment

The purpose of this experiment was to test whether self-explanation and analogical comparison of worked examples facilitates conceptual learning and problem solving transfer for students learning rotational kinematics in a classroom environment.

Methods

Seventy-eight students from the United States Naval Academy (USNA) participated as a part of their normal course work. The students participated from 4 sections of the introductory physics course taught at the USNA. The number of students in each section ranged between 18-26 students and the experiment took place during their normally scheduled lab time.

A between-subjects design was used with students randomly assigned to one of three learning conditions: reading ($n = 26$), self-explanation ($n = 26$), and analogy ($n = 26$). The lab session was divided into a learning and test phase.

Learning Phase. The learning materials were presented in paper booklets. All participants received a principle booklet that gave an introduction to the principles and concepts of rotational motion (e.g., angular displacement, angular velocity, angular acceleration, etc.). The principles each had written descriptions, graphic illustrations, and formulae. Students were given 9 minutes to read through the introductory booklet and had access to it through the entire learning phase. Participants were then randomly assigned to one of the three learning conditions (reading, self-explanation, and analogical comparison). Each condition received a learning booklet.

The booklet for the *reading* condition consisted of six worked-out examples (word problems with the step-by-step solution) that included detailed explanations and principle justifications for each solution step. Part of the solution to the worked example was left blank for the participants to fill in. The problems were presented sequentially and the participants' task was to read aloud the problem filling in the blanks as they went. They were then given the solutions to the fill-in-the-blanks and repeated this procedure for the second worked example. Next, they solved two isomorphic practice problems (one more problem than the other two learning conditions to control for time on task). This procedure was then repeated for the remaining two sets of worked examples. The learning booklet for the *explanation* condition consisted of the same six worked examples. However, the participants in this condition were not given the explanations right away but were first instructed to try and generate the explanation and principle justification for each step. After generating their explanations they read through the 'expert' explanations (the same ones given to the reading group). After generating and reading through the explanations for the two worked examples they solved one isomorphic practice problem. They then repeated this procedure for the remaining two sets of worked examples. The booklet for the *analogy* condition used the same worked examples and explanations as the reading booklet without the fill-in-the-blanks. After reading the worked examples they were asked to compare and contrast the two examples writing out the similarities and differences between them. These compare and contrast questions were designed to focus the learner on various aspects of the underlying concepts. They then solved one practice problem and repeated this procedure for the remaining two sets of problems. The total training time was 55 minutes.

Test Phase. After the learning phase all participants were given a test to assess their understanding of the concepts. The test booklets consisted of three sections including a multiple-choice test (13 questions) and two problem solving tasks. The multiple choice test assessed qualitative reasoning and conceptual understanding. The problem solving tasks assessed application of the concepts in new contexts. The first problem was to apply the concepts in a slightly different way than they had practiced during the learning phase (a different set of steps) and in a new context (cover story). The second problem was similar in structure to one of the worked examples however it included some new irrelevant information (extraneous values) and a new context (cover story).

Results

Test performance was highly variable within each condition. To best assess the effects of instruction on test performance we examined the upper half of the learning performers within each condition (median spilt of the practice problem scores). Test performance for the high learners in each condition is shown in Table 1.

Table 1: Mean Test Performance for the High Learners for Each Condition.

Training	**Test**		
	Multiple Choice Conceptual	**Problem Solving 1** New Context / Diff. Steps	**Problem Solving 2** New Context / Extra Info
Reading (n = 13)	.51	.77 (***d*** = .70)	.51
Explanation (n = 13)	.59 (***d*** = .45)	.76 (***d*** = .70)	.71 (***d*** = .69)
Analogy (n = 13)	.59 (***d*** = .48)	.55	.75 (***d*** = .86)

Discussion

The results are consistent with the laboratory predictions and show that self-explanation and analogical comparison can support conceptual learning in a classroom setting. Both the self-explanation and analogy groups showed conceptual learning gains beyond the traditional worked example group on the multiple-choice test (Cohen's d effect size scores of .45 and .48 respectively). The results for the problem solving tests were more mixed. The reading and explanation groups showed an advantage over the analogy group on problem 1 whereas the explanation and analogy group performed better on problem 2. The reading group was expected to perform closer to the other groups on problem solving because they had more practice (solving an additional practice problem during learning). Current work examines the solutions in more detail to differentiate conceptual from procedural errors.

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