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Authors
Trumpower, David L.
Goldsmith, Timothy E.
Williams, Bryan J.

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David L. Trumpower (dtrumpow@unm.edu)
Timothy E. Goldsmith (gold@unm.edu)
Bryan J. Williams (asnjoe@unm.edu)
University of New Mexico
Department of Psychology, Logan Hall
Albuquerque, NM 87131 USA

Introduction

Structural, or conceptual, knowledge is defined as the knowledge of concepts and their interrelationships with one another. Although it has been shown that structural knowledge is predictive of expertise (e.g., Goldsmith, Johnson, & Acton, 1991), questions remain about how it develops, especially with respect to procedural knowledge. For example, Rittle-Johnson, Siegler, and Alibali (2001) propose that procedural and structural knowledge develop in an iterative fashion, with increases in one leading to increases in the other. The current studies, however, explore a situation in which procedural training leads to better problem solving performance but impaired structural knowledge.

Method

Undergraduate students enrolled in an Introductory Psychology course at the University of New Mexico participated in this study for partial course credit. None of them had previously completed a college-level physics course.

The procedure for all of the experiments reported here were the same except as stated otherwise. Participants were first asked to rate the relatedness of all pairwise combinations of eight physics concepts from the subdomains of kinematics and dynamics on a 5-point scale (1="Not at all related", 5="Very related"). This served as a baseline measure of participants' structural knowledge. Participants were then asked to study two completely solved physics word problems. Participants were given two minutes to study each problem. Next, they were asked to solve six similar physics problems. They were given five minutes to solve each problem, and were allowed to use an equation sheet as well as the two solved examples to help them. After completing this training session, participants were asked to complete the ratings task a second time in order to measure any change in structural knowledge.

Results & Discussion

In Experiment 1, participants showed a significant linear decrease in time to solve problems across trials, $F(1,45)=18.81$, $p<.001$. Relatedness ratings were transformed using the Pathfinder scaling algorithm (Schvaneveldt, 1990) into a network representation of each participant's structural knowledge. Resulting networks were then compared with a referent network derived from averaged ratings of three physics experts. Surprisingly, structural knowledge representations were significantly less similar to the referent after training, $F(1,45)=9.78$, $p<.01$.

In Experiment 2, participants were required to think aloud while completing the rating tasks. Again, participants' structural knowledge representations were significantly less similar to the expert referent after training, $F(1,7)=3.89$, $p<.10$, despite showing a linear decrease in time to solve problems, $F(1,7)=6.68$, $p<.05$. Analysis of verbal protocols reveals that before training participants' ratings were more likely to be based on real world explanations, whereas after training they were more likely to be based on information from the problems (e.g., equations).

In Experiment 3, participants were required to learn all of the equations necessary for solving the problems before training began. Despite memorizing the equations, participants' structural knowledge again got worse after training, $F(1,8)=5.69$, $p<.05$, while their procedural performance got better, $F(1,8)=5.66$, $p<.05$. This rules out the possibility that participants' structural knowledge appeared worse after training in Experiments 1 and 2 because they attempted to base their ratings on equations, but had not adequately memorized them.

Based on the verbal protocols, it is suggested that novice physics problem solvers can have a somewhat accurate understanding of the real world and of mathematical equations, but difficulty integrating the two. A protocol from one of the participants illustrates this disconnect between equations and the real world, "distance and time...those are two things that are related, but they don't come directly into play...give those a 2 just because, well, by directly into play I mean that one doesn't affect the other, unless it's on paper".

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