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Chi M T H, Feltovich P J & Glaser R. Categorization and representation of physics problems by experts and novices. *Cognitive Sci.* **5**:121-52, 1981.
[Learning Research and Development Center, University of Pittsburgh. PA]

The mental representation of physics problems was investigated in experts and novices. Results from sorting tasks and protocols revealed that experts initiated problem solving by abstracting physics principles, suggesting that their problem schema were organized around the principles, whereas novices approached problem solving on the basis of the problem's literal surface features. [The *SSCI*® and the *SCI*® indicate that this paper has been cited in more than 375 publications, making it the most-cited paper published in this journal]

Experts' vs. Novices' Knowledge

Michelene T.H. Chi
Learning Research and Development Center
University of Pittsburgh
Pittsburgh, PA 15260

When Bob Glaser, the codirector of the Learning Research and Development Center, asked if I would be interested in writing a research proposal with him on the topic of expertise, I could hardly say no, given that I had just completed a relevant study.[1] I decided to illustrate the role of knowledge in a complex problem-solving (rather than a memory) task (as was done in reference 1). Physics was chosen partly because several publications were emerging concerning the differences between experts and novices in the way they solved physics problems. Most notable was the publication by D.P. and H.A. Simon[2] showing that experts tended to work forward from given quantities, and novices tended to work backward from sought quantities. Rather than a strategic difference, I interpreted these results as reflecting a difference in the representations of experts' and novices' knowledge structures. But who was I, a new graduate of Carnegie-Mellon University, to challenge Herb Simon's findings! The courage came from discussion with Bob, funding from the Office of Naval Research (ONR), and reinforcement from Paul Feltovich, who joined our group in 1978.

The conjecture of a knowledge-based difference in the representation of problems required a methodology that did not focus on processing differences. Consequently, a method of sorting physics problems on the basis of their perceived similarity was used. Subjects' explanations for the basis of their groupings were collected as well. Although a cluster analysis could easily identify which problems were sorted together by novices and experts, making sense out of the groups became more problematic.

Anxious about the upcoming talk for an ONR contractors' conference, I decided to focus only on those subsets of problems that the majority of experts and novices grouped together. Scrutinizing this smaller sample, a dramatic difference between the problems grouped by the novices and those grouped by the experts suddenly emerged. It was clear that novices sorted together problems that "looked" alike, but experts did not. This suggested that novices sorted according to the concrete objects mentioned in the problems (e.g., pulleys); but it was not clear how experts were sorting. With the help of our bright undergraduate assistant, Andrew Judkis, who knew more physics than I, the experts' sortings were analyzed by examining their explanations. We concluded that experts mentally represented and directed their problem solving by the "deep" principles embodied in the problems. Although this interpretation must be correct at some level, we continue to elaborate on the characterization of the experts' deep level of representation of physics concepts.[3]

When the results were presented at the annual ONR contractors' conference, I was crushed when John Seely Brown remarked that we had not considered the procedural knowledge involved in the task. My ego was somewhat salvaged afterwards when Allan Collins, then the senior editor of *Cognitive Science,* asked us to submit this work. Additional studies were conducted to pin down and extend the initial findings, then the paper was submitted, but only to be turned down with requests for serious revisions. Intimidated, we procrastinated in making the revisions. To our surprise, several months later, after a change in editorship, Ed Smith called and asked about the status of the revised paper. We took this inquiry as a sincere encouragement to resubmit. Thus, the publication of this paper owes much to the initial solicitation from Al, and subsequent endorsement from Ed. Now myself a senioreditor of *Cognitive Science,* I hope I have the foresight that Al and Ed did in recognizing a promising piece of work.

The basic expert-novice result, that experts' knowledge is represented at a "deep" level (however one characterizes "deep"), while novices' knowledge is represented at a more concrete level, has been replicated in many domains, ranging from knowledge possessed by scientists to taxi drivers. This result can also be used to interpret findings in many related cognitive science topics, e.g., analogical reasoning, and concepts and categories.

1. **Chi** M T H. Knowledge structures and memory development. (Siegler R, ed.) *Children's thinking: what develops?* Hillsdale. NJ: Erlbaum. 1978. p. 73-96.
2. **Simon D P & Simon H** A. Individual differences in solving physics problems. (Siegler R. ed.) *Children's thinking: what develops?* Hillsdale. NJ: Erlbaum. 1978. p. 323-48. (Cited 95 times.)
3. **Chi M T H** & **Slotta J.** The ontological coherence of intuitive physics: commentary on A. diSessa's 'Toward an epistomology of physics." *Cognition Instruct.* l0(2-3):249-60, 1993.

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