Rethinking the Role of External Representation in Problem solving

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The so-called "cognitive revolution" of the mid-1950s has resulted in extensive research on *internal* cognitive processes. Researchers studying different areas of human cognitive functions were typically focused on both the contents and processes that occur inside the head. Newer approaches, like situated action and distributed cognition, question the information-processing approach to the understanding of human problem solving and knowledge. They emphasize external representation, both in the physical and social world, over internal representation in various kinds of human activities. Under the influence of the two newer approaches, studies demonstrating the importance and facilitation effects of external representation have increased in number (Gero, 1998; Scaife & Rogers, 1996; Suwa & Tversky, 1997; Zhang, 1997; Zhang & Norman, 1994). They focus on the study of the tasks and situations in which the activities are performed.

Studies by Zhang and his colleagues (Zhang, 1997; Zhang & Norman, 1994) showed the positive effect of externalizing rules in solving traditional cognitive problems. Architectural design research also emphasizes the interaction between external representation and internal representation (Gero, 1998; Suwa & Tversky, 1997). However, observation from a study by Vera, Kvan, West, and Lai (1998) on architectural design showed similar design process by participants using distinct ways of representing the problem.

In this study, eighteen pairs of participants worked on the Twelve Balls Problem[1], a cognitive problem not like other traditional ones such as tic-tac-toe isomorphy or missionaries and cannibals, for forty-five minutes under chat line, audio video, or face to face condition. They were allowed to freely represent the problem on a shared electronic whiteboard. Some pairs solved the problem through representing the problem solving in tree diagrams, while others used production rules, or actual manipulation of drawn balls.

Verbal protocols between pairs of participants were coded into six categories for the analysis of the quality of their problem solving. Three of the categories are good indicators of problem solving, i.e. *Meta-rule*, *Both Possible Outcomes Evaluated*, and *Path Ruled Out*, that help the participants move toward the solution. Three other categories, *Improper Move*, *Unbalanced Strategy*, and *Guess* are of bad problem solving in that they don't move participants toward the solution. Analyses were done comparing differences between groups with and without using a particular representation on the indicators mentioned above. No significant difference was found. The number of ideas was also counted in order to compare differences between using and not using a particular representation and the result was also not significant.

There was no dramatic impact of external representation found in this study. Even pairs using very distinct modes of representation did not differ much from each other in their problem space search. In general, tree diagram representation and forms of production rules are abstract ways of exploring possibilities and relations of different tasks. They differ significantly from the creation and manipulation of explicit objects and manipulating them. The similar problem solving behaviors displayed by pairs in this study suggest that the link between external representation and better performance in various tasks is not as simple and direct as it appears at first glance. With the different types of representation used, participant pairs did not differ in generating more ideas, having more reflective thoughts on the problem, or in better avoiding useless moves. Aside from being more complex, the Twelve Balls Problem is not inherently different from the kinds of problems and isomorphs that have been studied in recent distributed cognition work. There is no *a priori* reason to expect that representation would have no effect in this task.

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[1] We are grateful to Chris Schunn and David Klahr for introducing us to this problem.