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Encoding and Response Strategies in Complex Skill Acquisition

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The study of skill acquisition has focused primarily on high-level cognitive mechanisms needed to acquire and adapt problem-solving knowledge. However, many skills also involve complex low-level processes of visually encoding relevant information and generating an appropriate response. Our work uses a low-level analysis of visual encoding and response data to show that the acquisition and adaptation of encoding and response strategies play a significant role in complex skill acquisition. It also supports recent findings concerning the importance of information reduction in skill acquisition (Haider & Frensch, 1996).

For our analysis, we use data from a task where students learned and used equations from a simplified textbook-like presentation. In the experiment, subjects solved simple physics problems using equations and examples to guide their solutions; the problems resembled simplified versions of more complex physics problems in similar studies (e.g., Chi & VanLehn, 1991). We are primarily interested in the skills needed to encode the equation, to encode values from the given test problem, and to generate a correct response based on the equation and values.

Our approach to analyzing encoding and response strategies makes heavy use of eye-tracking data. Recent research in reading comprehension (Just & Carpenter, 1984), word problem comprehension (Hegarty, Mayer, & Green, 1992), and arithmetic performance (Suppes et al., 1982) has shown that visual data can provide many insights into cognitive skills. This research has primarily analyzed visual data in aggregate—for example, the number of fixations in a particular area or the number of re-readings after an initial reading. Our work examines subject behavior in aggregate as well as at the level of individual scanning and response protocols. Such a protocol analysis is analogous to verbal protocol analysis common in the field, and can be helpful in elucidating subject strategies which may be subtle or hidden in an aggregate analysis.

The data analysis illustrates at least two interesting aspects of subject behavior in the task. First, subjects adapted their encoding strategies both between and within blocks of problems to produce more efficient scanning patterns. Second, subjects used domain knowledge to specialize their encoding and response strategies. These results also show that subjects can limit information processing to relevant aspects of the task, demonstrating the importance of information reduction in skill acquisition.

These results have important implications for general theories of cognition. They suggest that such theories should be able to acquire and adapt low-level skills, to learn how and what to encode based on presentation of information and past domain knowledge, and to decide whether to output the response during or after computation. The ACT-R theory (Anderson, 1993) seems well-suited to address these challenges. ACT-R allows for the creation of low-level production-system models that can use both visual information and domain knowledge to adapt strategies. We are currently experimenting with an ACT-R model of the task to ascertain its ability to account for these data.

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