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The Essential Role of Mental Models in HCI: Card, Moran and Newell

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Introduction

In the formative years of HCI in the early1980s, researchers explored the idea that users form mental models of computer systems which they use to guide their interaction with the system. This was a powerful concept because it meant that if we, as interface designers, understood what kind of model the user constructed as well as the process of constructing it, we could make computers easier to use by developing systems that were consistent with that model or that made it easier to construct the model.

In this brief essay I examine a concept of mental models put forward by Card, Moran and Newell (1983) in their book, *The Psychology of Human-Computer Interaction*, and explore its impact on the science and application of HCI. This book and subsequent papers had a strong and lasting influence on the field of HCI as an applied research discipline because it provided a testable theory that bridged the divide between psychological theories of human processing and the emerging discipline of interface design.

> *Our purpose in this book is to help lay a scientific foundation for an applied psychology concerned with the human users of interactive computer systems. Although modern cognitive psychology contains a wealth of knowledge of human behavior, it is not a simple matter to bring this knowledge to bear on the practical problems of design – to build an applied psychology that includes theory, data and methodology*. (Card, Moran and Newell, 1983).

Mental Models

The concept of mental models had special meaning for me when I entered the field of HCI in the 1980s. I had recently completed my doctoral work in cognitive psychology studying language comprehension with Phil Johnson-Laird at Sussex University in England. Johnson-Laird had advanced the theory of mental models to explain how people construct internal representations of meaning from which they infer semantic relationships (e.g. Johnson-Laird, 1983). Although the theory was developed within cognitive psychology, it was influenced by cognitive science which had been embraced by our department. Cognitive science and the funding behind it, supported cross-disciplinary research at the intersection of psychology, linguistics, artificial intelligence and philosophy.

Around the same time, another group of researchers were proposing that users form mental models of computer systems which they use to guide their interaction (e.g. Norman, 1983). In cognitive science, mental models were assumed to apply to some kind of abstract representation in people's heads. In HCI, mental models were more concrete although still representational. These models variously referred to a) the actual model of the system; b) the engineer's model of the system which then drives the technical design and implementation; c) the user interface designers' model of the system and, d) the user's model of the system.

Being steeped in theories of mental models and cognitive science I was primed to look for new ways to apply what I had learned. The opportunity came when I was a post-doc in the AI department at Yale University working with Eliot Soloway on researching expert-novice differences in programmers. We attended the 1982 Conference on Human Factors in Computing Systems in Gaithersburg, Maryland, widely regarded as the first HCI conference (although neither HCI nor CHI had yet been named). I remember the excitement of finding people from vastly different disciplines of psychology, AI, computer science, and social sciences all interested in the same set of topics about users, computer systems and the interaction among them. Although the Card et al book was yet to be published there were several presentations and lots of hallway discussion of this new approach to human computer interaction. I was shortly to start a career in industry, working to improve the usability of new systems and applications; a theoretically grounded approach was just what I was looking for.

From early on, mental models were used in HCI to provide a theory of the user's representation of the system as well as ways of designing a system that would influence the content of the user's model as well as its construction. For Card et al, who were pursuing the goal of developing a theory of applied psychology, it was important that any concept of mental model not only be theoretical grounded but also be testable. They sought to explain and predict human-computer interaction by appealing to a type of model called GOMS, which is a method for describing the set of tasks the user wants to perform and their plans for performing it. In terms of the types of mental models outlined earlier, GOMS was a way to explicitly represent the user's model of the system in a way that helped to distinguish, but not direct, different design options.

GOMS stands for Goals, Operators, Methods and Selectional Rules.

- *Goals.* Goals represent the set of things the user wants to do using the computer, such as edit a document.

- *Operators.* Operators are the actions that belong in a user's repertoire of skills and the set of commands or operations that the system will let the user perform. At the time that GOMS was developed, operators would have been keyboard commands.

- *Methods.* Methods correspond to the sequence of subgoals and operators to achieve the goals. If the goal was to edit a document, a sub-goal might be deleting a section of text. The method to achieve this goal would be described at the level of the individual actions and even keystrokes that the user would perform, beginning with placing the cursor at the beginning of the deletion point, holding down the mouse, dragging the mouse across all the text to be deleted to select it, raising the mouse and clicking the delete key.

- *Selectional rules.* Some goals could have multiple methods. For instance, instead of using the mouse to select text for deletion, the user could use the keyboard arrows to select the text. The model included a process for selecting amongst the different methods.

In keeping with its goal of linking theory with research, the GOMS model was used to predict performance for "routine cognitive skills" such as text editing. The theory, which focused on skilled users, was supported by research on text editors which demonstrated that the same task took longer using the text editor with the predicted greater number of operations (Roberts and Moran, 1983). A simplified version of GOMS, the Keystroke model, cast GOMS at the level of individual keystrokes to explain and predict expert error-free performance. The original model was further elaborated to provide more rigor as well as sets of tools to automate parts of the analysis process (see e.g. John and Kieras, 1996). Although the model provided testable theories it also came under a lot of criticism for its focus on low-level operations, highly skilled users, error-free performance and an inability to take into account individual differences, effects of fatigue or motivation (e.g. Olson and Olson, 1990). Despite some of the shortcomings there continues to be active research extensions to the GOMS model (see e.g. John et al, 2002).

Evaluating the influence of Card, Moran and Newell

Although the particular details of the Card et al theory may fall short by focusing too much on low-level tasks by skilled users it provided a systematic and principled set of quantitative and qualitative predictions about the ease of use of a particular interface design. It thus established much of the theoretical foundation of HCI and its place as an applied discipline with contributions to the theory of interaction as well as to the practice of interface design and usability testing. The GOMS formulation also provided HCI researchers and practitioners with tools for building models of human behavior, many of which have found their way into areas such as usability testing with its emphasis on task modeling and performance. In fact, usability has grown from a thematic area in HCI to a separate group with its own society (Usability Professionals Association), conferences, events and magazine.

As UI design standards and design guidelines started to infiltrate the HCI practitioner community in the early 1990's, the role of mental models as a guiding principle began to decline in favor of approaches that focused on the "look and feel" of the interface. This has not meant that an engineering approach has entirely disappeared from HCI. As recently as the 2006 Conference on Human Computer Interaction there was a panel – *Real HCI: What it Takes to do HCI Engineering for Disasters, Driving, Disruption, and Distributed Work* – that called for an engineering approach to HCI practices including a re-examination of tasks and models to frame the design space and predict outcomes.

Looking back at what I consider to be one of the most influential bodies of work in HCI, I believe that Card, Moran and Newell's work, reinforced my commitment to HCI. They demonstrated that there were a set of interesting problems that required a deep understanding of people combined with an appreciation of the opportunities of new innovative technology for the solution. They convinced me that we could advance our theoretical understanding of technology and interfaces but also contribute to the practical design and implementation of new products and services.

But the role of mental models including Card et al, has not advanced without controversy. There is an inevitable tension between the psychologists, computer scientists, engineers and designers who make up the HCI field. Discussion of mental model brings up the lingering debate over whether science, engineering or design drives HCI. Do theoretical concepts such as mental models as representation really contribute to the practical issues of interface design or system engineering or are they a distraction? Where is the real "science" in HCI? Can science and design co-exist? These are questions that the next generation of HCI will continue to ponder.

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