Catalysts to creating representational tools and the benefits for learning

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Abstract: Thirty-two undergraduates and six graduate students participated in a medical diagnosis task. They received a set of reference cases and diagnosed new patient cases by ordering and considering the results of medical tests. Half of the participants faced a memory burden as they worked on an initial set of ten new patient diagnoses. Participants then taught a confederate how to perform diagnoses. Finally, two new diseases were introduced, and participants diagnosed five new patients. Participants were allowed to take notes throughout the study. Both the memory burden and the teaching demand led participants to create external representations. Representations used for initial diagnosis, but not for teaching, carried over into the final diagnosis set. Results show that creating a representation was initially inefficient, but led to better performance and learning when participants were asked to adapt to new diseases. Also, a much greater proportion of graduate students than undergraduates created representations.

Introduction

Kirsh (1996) notes that "introducing a tool is one of the easiest ways to change an agent's action repertoire, for now it is possible to do things previously unattainable, or unattainable in a single step" (p. 438). Because the introduction of a tool fundamentally alters the possibilities for action within a problem space, it is an important external adaptation that changes one's own possibilities for action, thought, and communication. This study examines the creation and use of one important class of tools: representational tools, such as trees, diagrams, and tables. Representational tools are important in the work of many disciplines, and they are important in education as well. We are interested in the factors that motivate people to make representational tools and in the effects these tools have on learning and problem solving. Our study is designed around a medical diagnosis task that allows participants to succeed with or without the use of a representational tool. We focus on two research questions:

1. What factors influence whether or not people create a representational tool?
2. What are the effects of participant created representational tools on problem solving and preparation for future learning?

We predicted participants would be more likely to create a representational tool if 1) they could not rely on the situation to support their "unaided" cognition, and/or 2) they had to teach a confederate to complete the task. We also predicted that creating a representational tool might initially impair performance, but would prepare people to learn more quickly when given modified problems.

Design and Procedure

Thirty-two undergraduate students with no medical training participated in a medical diagnosis task. Participants received a set of twelve reference cases. Each case resembled a simple medical chart, with medical tests and associated results. The participants' task was to use the reference cases to diagnose new patients with one of the six diseases represented in the reference cases. For each patient, participants could order a variety of medical tests. They were told to minimize the number of tests ordered for each patient. Blank paper was available for note taking at all times.

Participants were randomly assigned to one of two conditions: the *continuous access* condition or the *intermittent access* condition. In Part 1, *Original Case Set*, participants solved 10 cases or worked for up to 30 minutes. Those in the intermittent access condition were told that they could look at the reference cases as much as they wanted to between diagnoses, but they had to place the reference cases face down while performing a diagnosis. Those in the continuous access condition were allowed unrestricted access to the reference cases. Otherwise, the conditions were identical. In Part 2, *Teaching*, participants taught a confederate how to perform diagnoses. In Part 3, *Novel Case Set*, two new diseases were introduced, for a total of eight diseases, and participants

diagnosed five new cases. The new cases included both old and new diseases. Importantly, for the Novel Case Set both conditions had continuous access to the reference cases, so it is possible to see if the earlier manipulation would have a lasting effect even when the condition differences were removed.

Data sources included the order in which tests were requested, the final diagnosis, the time spent on each diagnosis, and any representations that were created by the participants. Data on the order in which tests were requested was further coded to determine the optimality of their search..

Results and Discussion

Across the conditions, participants created a variety of representations including ordered lists and decision trees. Representations were coded into three categories: If-Then, when representations included if-then rules; Simple List, when representations did not include if-then rules; and No Tool, when no notes were made. The contrast between conditions had an effect on the frequency of representational tool creation or modification (see Table 1).

Table 1: Creation and Modification of Representations by Condition

Condition	Representation	Part of the Experiment		
		Original Case Set	Teaching	Novel Case Set
	No Tool	13	6	13
Continuous Access	Simple List	2	0	2
	If-Then	1	10	1
	No Tool	2	5	4
Intermittent Access	Simple List	12	4	7
	If-Then	2	7	5

Notably, participants in the intermittent access condition were more likely than those in the continuous access condition to create or modify a representational tool in Part 3, Novel Cases, even though both conditions had identical instructions and identical access to resources during this part of the experiment. Those who created tools for the Original Case Set tended to modify them for Novel Cases, and those who did not create tools for the Original Case Set did not create them for Novel Cases. Teaching a confederate led many participants to create a representation. However, for those participants in the continuous access condition, creating tools for teaching did not lead to tool use or creation for the following Novel Case Set. It appears that tools for teaching do not necessarily translate into tools for doing.
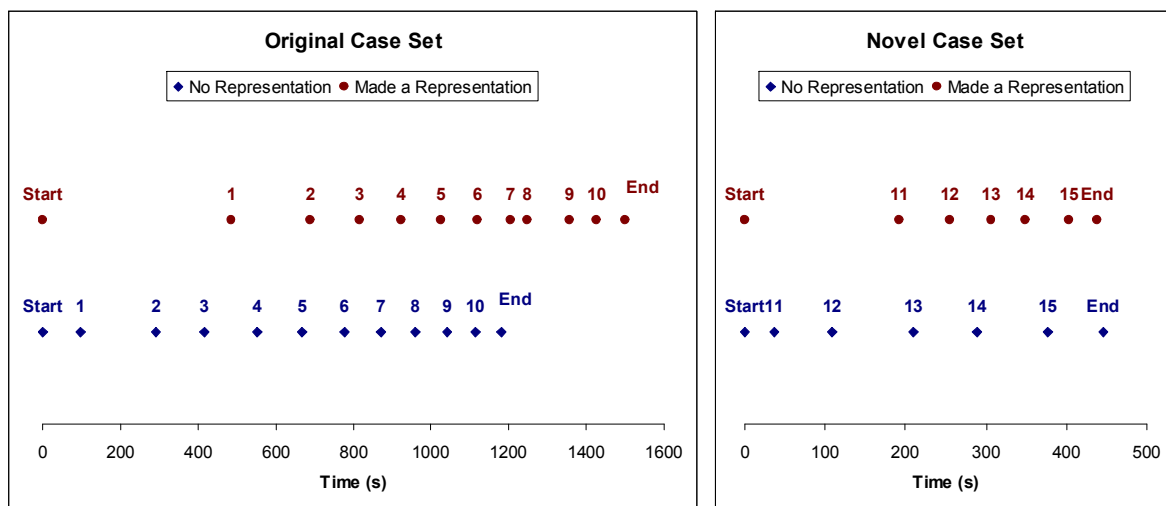
Figure 1. Time Course and Creation of Representations

Problem solving speed gives a rough indication of the implementation cost of creating a tool. Figure 1

shows when participants who did and did not create representations began each diagnosis problem. Participants who created representations for the Original Case Set were slower to begin the task, and finished later than those who did not create representations. However the inefficiency of creating a representation was only temporary. Those who created a representation for the Novel Case Set again began working on the first problem later, but they finished at approximately the same time as those who did not create representations. That is, despite the initial time cost of creating representational tools, participants who created representations caught up by the end of the experiment.

By design, there was little variation in accuracy across participants, but there were variations in the optimality of participants' diagnoses. Each diagnosis was scored with a weighted optimality ratio: a measure of how close the diagnosis came to a perfectly optimal choice and ordering of medical tests, with a maximal score of 1.0. The contrast between conditions was not strongly associated with differences on this measure. However, creation of a representational tool did predict performance. Figure 2 shows participants' performance over time, with participants grouped by the most structured type of tool that they used for diagnoses. The optimality of performance was mediated by the presence of a representational tool: those with If-Then tools outperformed those with No Tool or a Simple List.
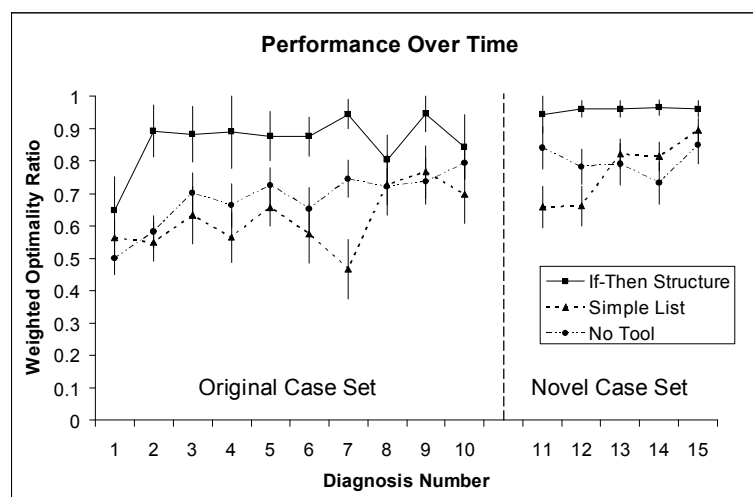

Figure 2. Task Performance by Type of Tool

Finally, data from a sample of six graduate students provides an interesting point of contrast. While only 19% of undergraduates in the continuous access condition created a representation for the Original Case Set, 100% of graduate students in the same condition did so. Although the underlying cause of this difference cannot be directly inferred from the data, the result suggests that graduate students may have developed an adaptive form of representational expertise for dealing with complex information management tasks such as this one.

Conclusion

These results suggest the power of representational tools, not only for efficient problem solving, but also for adapting to new problem demands. The experimental contrast influenced problem solving and preparation for future learning, as mediated by the representational tools that participants created. Surprisingly, tools for teaching did not necessary translate into tools for doing. Experiences creating and using representational tools increased the chances of doing so again in the future, both within the context of the experiment, and, we presume, over longer timescales, as shown by the contrast between undergraduates and graduate students.

References

Kirsh, D. (1996) Adapting the environment instead of oneself. *Adaptive Behavior*, *4*, 415-452.

Acknowledgments