Goals and problem solving: Learning as search of three spaces

Bruce D. Burns and **Regina Vollmeyer**
Institut für Psychologie
Universität Potsdam
14415 Postdam
Germany
{burns,vollmeye}@rz.uni-potsdam.de

A recent trend in computer-based learning has been to set up systems that the learner explores, rather than setting very specific goals to reach. Our previous research on complex problem solving has supported this approach (Vollmeyer, Burns, & Holyoak, 1996). When learning how to control a system with a set of inputs linked to a set of outputs, participants learned more about the system when they were given a nonspecific goal rather than a specific goal. These results could be explained using Simon and Lea's (1974) dual-space framework (or that of Klahr & Dunbar, 1988, who extend this framework to scientific discovery) in which induction is seen as a search of instance space (i.e., examining states of the system), integrated with search of rule space (i.e., formulating and testing rules that might govern the system's behavior).

Protocol analysis by Vollmeyer and Burns (1995b) provided evidence that a specific goal increases search of instance space, while a nonspecific goal increases search of rule space in that it increases the amount that problem solvers test and modify hypotheses. The protocol studies also suggest why some problem solvers do very poorly: they test rules that are impossible. Thus a third type of search can be proposed, search of model space. The problem solver's model defines the rule space so if a learner has the wrong model, search of rule space will be ineffectual and they may learn more from search of instance space.

A test of a multispace model

To test if model space is separate from rule space, we manipulated the model participants had as well as their goals. Participants were given an input/output system similar to, though simpler than, that used by Vollmeyer et al. (1996). This task required problem solvers to control a system that consisted of a set of outputs (water quality measures in a tank) that could be manipulated by a set of inputs (catalysts). The inputs had weighted links to the outputs. Presented in Figure 1 are the links, which were not shown to the participants. Similar to Vollmeyer et al., participants were given a specific goal (they were told at the beginning the exact goal values they would later try to reach) or a nonspecific goal (they were not told the goal until they had to reach it). In addition, we manipulated the model that participants had of the task by giving them a good or poor model of the task. Protocol analysis by Vollmeyer and Burns (1995b) found that one type of incorrect hypothesis tested was that inputs interacted, although none did. Accordingly, in this experiment participants given a poor model of the task were told that inputs may interact. Participants given a good model of the task were told that there was no possibility of interactions between inputs because two catalysts were never put into the tank at the same time. We predicted an interaction between goal specificity and model type.

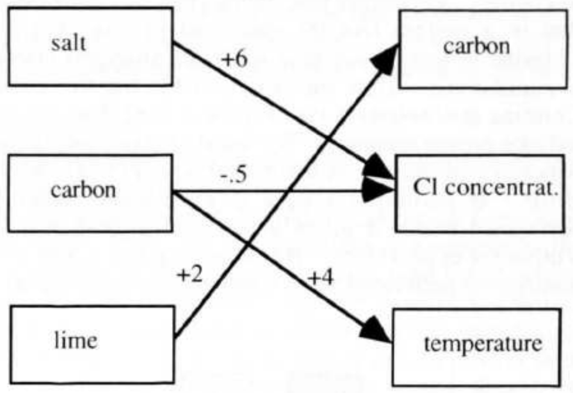

Figure 1: System used in the experiment.

Method

Participants. One hundred and eighty-six students at the University of California, Los Angeles participated in the experiment for course credit.

Procedure. A 2x2 design was used with the factors goal specificity (specific vs. nonspecific) and model (good vs. poor). Participants were given instructions appropriate to their condition; then they had two rounds of six trials each. On each trial participants could manipulate the inputs and observe the resulting outputs. At the end of each round participants completed a diagram on which they indicated what they knew about the structure of the system. From these diagrams a structure score was derived in the same way as described by Vollmeyer et al. (1996).

In the third round, participants tried to reach a goal, one which specific-goal participants had known since the beginning. Then all participants were given a new goal to reach in a fourth round. This goal tested how well participants could transfer what they knew to a new goal. Transfer error was a measure of how close participants got to this goal (see Vollmeyer et al., 1996).

Results and Discussion

As Vollmeyer et al. (1996) found, nonspecific-goal participants ($M = 2.36$) learned more about how the system worked than did specific goal participants ($M = 1.93$), as measured by structure scores, $F(1,182) = 8.83$, $p < .005$. However, there was no effect of model type on structure scores. These finding replicates the results of Vollmeyer et al. and suggests that nonspecific-goal participants searched rule space more, regardless of model type.

There were no significant effects of goal or model on transfer error, nor was there an interaction between these two factors (though the pattern was as predicted). However, there was a significant interaction between model type, goal specificity and output type. Because the Chlorine Concentration output is affected by two inputs, it is harder to control. Vollmeyer and Burns (1995a) found evidence that in a system like the one used in this experiment, Chlorine concentration may show the strongest effects of manipulations. Thus we examined the transfer error for Chlorine concentration (see Figure 2, note that low scores indicate greater accuracy). We found a significant interaction between goal-specificity and model type, $F(1,182) = 4.09$, $p < .05$. If participants were given a good model, they performed better if given a nonspecific-goal, just as in Vollmeyer et al. (1996). However, if given a poor model, participants performed better when given a specific goal.

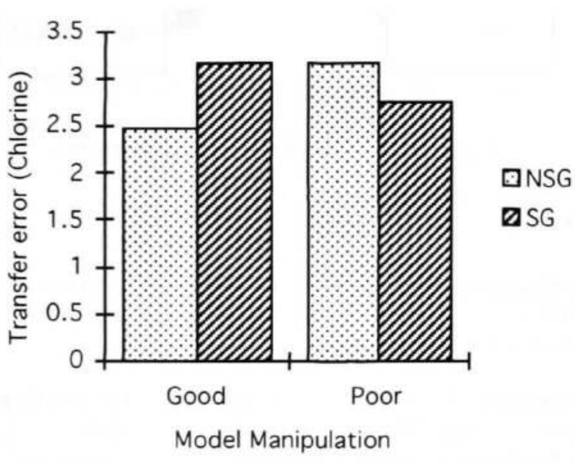

Figure 2: Transfer error for Chlorine concentration.

This experiment supports the theory proposed earlier, that in order to explain problem-solving behavior it is necessary to propose a three-space search. In this model search of model space defines hypothesis space, search of hypothesis space guides search of experiment space, and provides evidence for search of model space. Search of experiment space allows testing of hypotheses, and leads to the goal.

Implications

While we have proposed a three-space search theory, we are not committed to proposing only three spaces. There may be more than three conceptually different spaces, especially for other tasks. What criteria should be used when proposing separate search spaces? Conceptually, new spaces need to make sense, but ultimately empirical support for the existence of multiple search spaces must be found. If conceptually different types of search spaces exist then experimental manipulation at the level of different spaces should lead to different results. The experiment presented here is an example of how empirical evidence can be used to support the idea of separate search spaces, especially when it is possible to predict interactions between factors.

One weakness of the above results is that this experiment could not be used to established that movement is occurring between different models. Thus we did not demonstrate that actual search was occurring at the level of models. Further evidence is required, such as protocol analysis as in Vollmeyer and Burns (1995b), which showed that problem solvers searched different rules, and different instances.

These results, and multispace models in general have implications beyond problem solving and scientific discovery. Most obviously, if they can be generalized they have strong implications for learning. The results suggest that whether a specific or nonspecific goal is beneficial for learning will depend on how good is the learner's model of the task. Furthermore, these types of models suggest ways to understand results in other areas of cognition. For example, implicit learning of artificial grammar may be worse for someone looking for underlying rules, than for someone who does not look for rules (Reber, 1976). However, the result does not hold if the grammar is simple enough. In terms of our three-space model, participants in experiments with difficult grammars have a poor model of the situation. Search of rule space will therefore be ineffectual, so that a specific goal (i.e., focus on instances of letter-strings) leads to better learning.

One challenge for this research is to establish what makes model "poor". The key factor could be the relationship between the true hypothesis space and problem solvers' hypothesis space, but this proposal requires more research.

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