Abstraction in Disciplinary Problem Solving

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Abstract: Much research on abstraction in learning has focused on domain-general abstraction as a developmental capacity or as a process of knowledge construction. However, this does not capture abstraction that happens *in-the-moment* as students make sense of novel phenomena and problem contexts. We operationalize abstraction in-the-moment as the extent to which students integrate prior knowledge while manipulating and transforming a problem space, and propose 4 actions of changing abstractness: concretizing, manipulating, restructuring, and generalizing.

Keywords: problem solving, abstraction, science education

Problem statement

Although many researchers theorize deeply about abstraction, few present operational ways to study it, particularly in-the-moment. A dominant paradigm in science education defines abstraction as knowledge construction. However, knowledge construction can be difficult to observe, as it is a process that primarily occurs internally in the mind of a knower and over a period of time as the knower grapples with and constructs a new concept. In science education, students are often given novel problems to solve to facilitate this grappling process. We anticipate that (1) problem solving is a microcosm in which abstraction can be observed, and (2) actions students take in problem solving may be a precursor to knowledge construction and can be characterized as abstraction. Our work examines abstraction in physical chemistry problem solving, as physical chemistry is a discipline in which students primarily learn through problem solving and in which the abstractness of concepts is a documented barrier to student success. Our research seeks to answer the following research question: *How can we operationalize the process of abstraction in complex physical chemistry problem solving?*

Theoretical and methodological approach

We took a grounded theory approach to develop a working definition of abstraction (Glaser & Strauss, 1967). We began with an initial definition of abstraction as a process characterized by connecting knowledge from different sources to emerge new understandings (Scheiner, 2016; van Oers, 2001), and abstraction in problem solving as identifiable by actions students engage in to move forward in problem solving (Hershkowitz, Schwarz, & Dreyfus, 2001). To define problem solving, we relied on the 2 critical components of problem solving identified by Jonassen (2010): the problem solver's development of an internal representation of the problem (i.e., problem space) and the transformation or manipulation of the problem space to generate a solution. To bridge these, we looked for abstraction in how problem solvers used knowledge from different sources to manipulate and transform the problem solving. Furthermore, abstractness as a characteristic can be operationalized by the degree to which constructed representations were integrated with knowledge from other sources (Barsalou, 2005).

We developed interview situations to facilitate the emergence of abstraction with three design considerations. First, the interviews were teaching interviews, which have been used in studies of abstraction (Hershkowitz, et al., 2001) because they allow the interviewer to probe deeply what a participant is thinking, and to scaffold connections participants are capable of making but may not immediately notice. Second, the problem tasks consisted of seemingly disparate parts that had to be pieced together conceptually for participants to succeed in solving the problem. These problems related to the course content the participants were learning at the time, but were multi-disciplinary and covered content beyond the scope of what had been covered in the course, so participants could not rely on memory. Finally, we conducted both pair and individual interviews, because literature suggests that students working in pairs may solve problems at a higher level of abstractness than they do working alone (Schwartz, 1995). Undergraduates (n=19) enrolled in Physical Chemistry 2 (Thermodynamics and Kinetics) at a highly diverse public institution in the Northeastern US were recruited with IRB approval in Spring 2018 to participate in 2 teaching interviews, one pair and one individual.

Findings and preliminary conclusions

Because we operationalize abstraction as actions taken on the problem space, we looked for abstraction by identifying representations and prior knowledge students used and developed and how they connected these (Hahn & Chater, 1998; Sevian et al., 2015). We then developed concept maps to highlight how students connected and transformed these representations (i.e., how they abstracted). In the concept maps, we found 4 patterns in how representations were connected which correspond to actions (1) that represented meaningful progress toward a solution state and (2) which could be differentiated by their abstractness, e.g., how participants used the problem space and prior knowledge in their transformation of the problem space (see Figure 1).

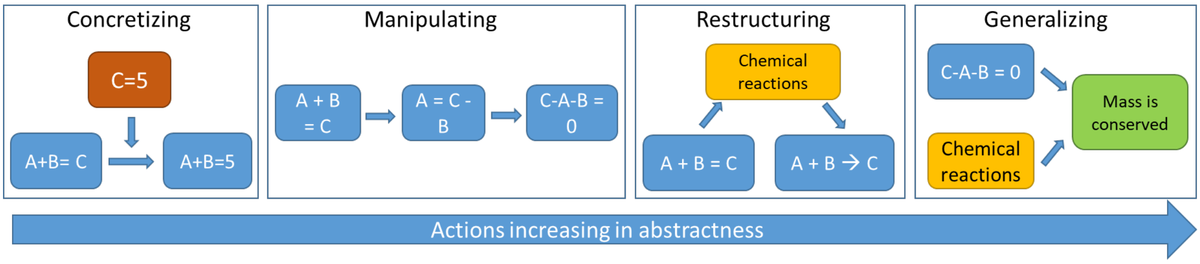

Figure 1. Examples of the common patterns found in the concept maps corresponding to each action.

The patterns found were: (1) ***Concretizing*****:** A constraint is placed on the problem space. The constrained problem space is then manipulated or transformed to move toward a solution state. A concretizing action results in something more concrete (less abstract) than the original problem space. (2) ***Manipulating*****:** Progress is made toward the solution state according to the rules and representations cued by the original problem space—e.g., if the original problem is identified as an algebra problem, manipulating encompasses the scope of what is typically done to solve an algebra problem. A manipulating action results in something at the same level of abstractness as the original problem space. (3) ***Restructuring*****:** The problem space is transformed, and this transformation is mediated through some piece of knowledge that was not cued by the original problem space. Thus, the resulting representation integrates prior knowledge and the problem space. A restructuring action results in something more abstract than the original problem space. (4) ***Generalizing*****:** Pieces of knowledge from the problem space and/or from the problem solver's prior knowledge are combined to yield something new that progresses toward a solution state. A generalizing action results in something more abstract than the original problem space.

This leads to several preliminary conclusions: first, a higher level of abstractness did not correspond to greater success or correctness in problem solving; in fact, abstracting when it was inappropriate often led students astray. Second, we anticipate that these actions are domain-general and can be used to interrogate problem solving in non-science domains. Ongoing work is focused on how sociocultural (e.g., interaction) and epistemological (e.g., framing) factors influence shifts in abstraction.

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