

A THEORY OF TEACHING AND ITS APPLICATIONS

Alan H. Schoenfeld¹
University of California, Berkeley

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Abstract: *Research methods and perspectives from a range of disciplines including education, psychology, artificial intelligence, and economics provide a set of tools for modeling complex human decision-making in fields such as teaching. This paper describes the foundations of such research and the underpinnings of a model of teaching-in-context that explains, on a line by line basis, the decision making by teachers during hour-long classroom lessons. The existence of such models provides tools for examining and improving teaching, as well as the possibility that the decision making in other professions can be comparably modeled.*

Introduction

Teaching, like many other professions – to give two very different examples, medical practice and automobile mechanics – depends on a large skill and knowledge base (1,2). Like such fields, its practice involves a significant amount of routine activity punctuated by occasional and at times unplanned but critically important decision making – decision making that can determine the success or failure of the effort. Moreover, how one goes about work in these professions is shaped in important ways by one's conscious or unconscious beliefs and values (3,4).

Methods and perspectives from a range of disciplines, including earlier studies of knowledge organization (5), problem solving (6) and decision making (7,8) have now been combined in ways that make it possible to provide theoretical characterizations of the behavior and decision making of practitioners in fields such as teaching. The theoretical approach has been tested by the construction of models that closely match the teachers' behavior over extended episodes of performance such as hour-long lessons (9,10). The existence of such models offers promise of improving the profession, both from the perspective of understanding accomplished performance and identifying appropriate points of intervention as teacher develop during their careers.

Knowledge organization

It has long been understood that human memory is associative, and that knowledge comes in associative "packages" that, depending on the field and intellectual tradition, have been called scripts (11), frames (12), routines (13), or schemata (14). For example, early research in text comprehension showed that when people read stories, they add to the text additional information based on stereotypical experiences: for example a person reading a story about a customer in a restaurant who enjoyed a meal but left a small tip will infer that the service was poor, even though no mention was made of the service (11); people

¹ Alan H. Schoenfeld
Elizabeth and Edward Conner Professor of Education
Graduate School of Education
University of California
Berkeley, CA 94720-1670, USA
Email: alans@berkeley.edu

reading the first three words of a problem statement, “A river steamer,” conjectured that the rest of the problem statement would be concerned with the boat’s speed moving with and against the current and the total amount of time it took to make a round trip (14). More generally, people invoke typical scenarios, and have “default expectations” regarding what is likely to take place, even though such information is not supplied. Similarly, teachers, doctors, and automobile mechanics make extensive informal use of diagnostic information to decide on next steps in professional interactions – as do we all, in social interactions, picking up subtle details and using them, whether correctly or not, to “fill in the gaps.”

Problem Solving

By the 1990s, researchers in mathematical and scientific problem solving, and more broadly in fields where actions are clearly “goal oriented” such as writing, had come to consensus about the categories of behavior that need to be examined in order to explain why people succeed or fail in their attempts at problem solving. The literature indicated that in any problem solving attempt, some or all of the following will be essential determinants of success or failure, and that (at this broad grain size) the list of factors was complete:

The knowledge base. Clearly, what you know and how you access it (cf. *knowledge organization*, above) is a major factor in how well you succeed at what you are trying to do. The knowledge base includes concepts and procedures, but also habits of mind and patterns of productive (or unproductive) behavior. But that can’t be all there is, as some people with less knowledge than others manage to solve problems that the people with greater knowledge don’t manage to solve.

Problem solving strategies. Such strategies, first described in mathematics by George Pólya (15) as “heuristic” strategies, are rules of thumb for making progress in understanding a problem or finding productive approaches to its solution. Heuristic strategies are seen in all fields of endeavor, and lie at the heart of many problem solving programs in artificial intelligence (16).

Metacognition (specifically, monitoring and self-regulation). Effective problem solvers keep tabs on how well their attempts are going and make adjustments on the basis of their assessments. Less effective problem solvers often fail to solve problems not because they don’t “know” the relevant material, but because they persevere at initial (often ill-conceived) plans, not giving themselves the opportunity to recover and pursue more profitable directions. This is one aspect of decision making (see below).

Beliefs, values, and orientations. In all fields of endeavor, our conscious or unconscious biases shape what we notice and what we choose to do. As Gropman notes in (3), such often unconscious biases shape the decisions made by doctors, ruling diagnostic possibilities in or out of contention. Similarly, problem solvers may choose or abandon paths based on aspects of their prior experience (17).

What the research on problem solving offered was a *framework* for characterizing the success or failure of decision making during problem solving. What it lacked was a complete description of mechanism, explaining how and why people made the specific decisions they made. (A partial answer was provided by research on routine knowledge access, but such work failed to account for decision making when circumstances were not familiar or when things were not going well.)

Decision making

Economists, among others, have long noted that human decision making is not rational (7,8). If it were, lotteries would go out of business; a straightforward calculation shows that the expected value of a lottery ticket is negative. The concept of *subjective expected utility* (7) provides a way of characterizing individual decision making in such cases. If the actual cost of a ticket is subjectively diminished for an individual (“this is pin money”) and the value of the reward is subjectively enlarged (“I’ll be rich, and I’ll be able to retire”), then the subjective expected value of a lottery ticket,

$$SEV = P(\text{loss}) \times (\text{Subjective cost of ticket}) + P(\text{win}) \times (\text{Subjective value of win}),$$

is positive, and the decision to purchase a ticket makes (subjective) sense. This notion can be generalized to provide subjective evaluations of various options an individual might consider.

Synthesis and Implications

First, teaching and problem solving can be seen as case examples of *goal-oriented* behavior, in which an individual establishes one or more goals and then sets about trying to achieve them. This kind of goal-oriented behavior characterizes many professions. Daily activity in such professions typically consists of the routine application of skills, punctuated by occasions that call for consequential decision making. In teaching, for example, many actions are developed as standard routines: lecturing, collecting homework, having students present work at the board or engage in group work, etc. Of course, which routines are established and how they are run will be a function of the teacher's beliefs and values: What (for this teacher) is the right balance of exposition and exploration? Can these students handle being confused, or is one better off laying things out for them? Is a quiet class a sign of something good or an indication of flagging interest?

A significant proportion of teachers' classroom activities can be characterized using the literatures on knowledge organization and problem solving. Established teachers have easy access to a range of routines for implementing everyday practices such as homework and board work. In addition, less frequent but important classroom teaching events often fit the same pattern. For example, every experienced algebra teacher knows that at some point in the course, a student will say or write the incorrect expression $(a + b)^2 = a^2 + b^2$. There are many possible ways to deal with this misconception. Given a teacher's experience and beliefs, he or she may have a few "favorites" among these approaches readily accessible in memory, and circumstances may determine which of these is actually chosen. Thus routine access to knowledge and strategies, along with appropriate metacognitive monitoring, suffice both for everyday and for less frequent but important classroom situations.

However, students sometimes come up with something new, e.g., an unexpected suggestion that, if pursued, would require a significant deviation from the lesson. The various options that come to a teacher's mind, ranging from "I'll talk to you about that after class" to "let's pursue that and see where it goes" all have costs and benefits. Different teachers will assess those costs and benefits differently. However, any particular teacher's judgments can be modeled by taking into account that teacher's subjective assessments of the costs and benefits of each option. This provides a quantitative mechanism for modeling the teacher's decision's decision making in these more rare but highly consequential situations.

A combination of the "access to familiar routines and strategies" perspective from research on knowledge organization and problem solving, and the "subjective decision making at critical times" perspective from the research on decision making provides the basis for the detailed modeling of teachers' classroom actions – and it does so at the level of explaining every utterance over the course of an hour's lesson. In simplest terms, the models work as follows:

A teacher enters the classroom with a particular body of knowledge, goals, and orientations (beliefs, values, etc.). The individual orients to the situation. Certain knowledge and routines become salient and are activated and/or triggered, and directions are established.

- Goals are established (or reinforced if they pre-existed).
- Decisions are made, consciously or unconsciously, in pursuit of top-level goals.
- Knowledge is selected for implementation. (Such knowledge may be in the form of scripts, routines, or schemata.) Implementation begins.

- Monitoring (whether effective or not) takes place on an ongoing basis.

The process iterates:

- If a subgoal is achieved, new subgoals kick in through the routine (or script, or...).
- If a goal is achieved, new goals kick in via decision making.
- If the processes is interrupted or things don't seem to be going well, decision making kicks into action once again.

The modeling approach described immediately above has been used to describe, in fine detail, a traditional high school lesson conducted by a student teacher (18); an innovative high school lesson on measures of central tendency (19,20); a college problem solving course, and a third grade discussion of the properties of even and odd numbers (21,22). Despite the variations in teacher style and experience, in students' age, and in classroom topics, teachers' in-the-moment decision making in all of these classrooms was captured in detail via the same basic approach, combining a dependence on (personally selected) routines with a form of expected value computation where the outcomes are assigned values consistent with the teachers' subjective views. In short, teachers' in-the-moment decision making (and, hypothetically, decision making in other professions with a similar balance of routine and consequential non-standard decisions) can be modeled.

The ability to capture individual teachers' decision making through such models has a range of potential applications. First, an understanding of the importance of various factors shaping such decisions, e.g., teachers' beliefs, has the potential for productive interventions: as in the case of problem solving (6), teachers' classroom actions are more malleable when the teachers become more aware of the (sometimes previously unconscious) causes of those actions and more reflective about them (23). Although the modeling process itself (at the level of line-by-line analyses) is very time consuming, its uses need not be: the same analytic approach can be used for discussions between teachers and their professional development coaches regarding which aspects of the teachers' practices are working effectively, and which could use some work. Long-term, this kind of modeling can be used to describe and analyze typical "developmental trajectories" for teachers as they become more experienced and accomplished, and to identify points in their careers when the teachers might be particularly receptive to (or need) particular kinds of interventions in order to keep developing as professionals. More broadly, given that the combination of knowledge-based and in-the-moment decision making in teaching is similar to that in a range of other professions, there is the possibility that the approach described here can be worked out in those fields as well.

References

1. L. Darling-Hammond & J. Bransford, Eds., *Preparing teachers for a changing world*. (San Francisco, Jossey-Bass, 2005).
2. M. Chi, R. Glaser, & M. Farr, Eds., *The nature of expertise*. (Mahwah, NJ, Erlbaum, 1988).
3. J. Groopman, *How doctors think*. (New York, Houghton Mifflin, 2007).
4. M. Lampert, *Teaching Problems and the Problem of Teaching*. (New Haven, Yale University Press, 2001)
5. D. Rumelhart & A. Ortony, The representation of knowledge in memory, in *Schooling and the acquisition of knowledge*, R. Anderson, R. Spiro, & W. Montague, Eds. (Mahwah, NJ, Erlbaum, 1977), pp. 99-135.
6. A. Schoenfeld, *Mathematical problem solving*. (Orlando, FL, Academic Press, 1985)
7. L. Savage. *The Foundations of Statistics*. (New York, Wiley, 1954)

8. D. Kahneman, P. Slovic, & A. Tversky. Eds., *Judgment under Uncertainty: Heuristics and Biases*. (Cambridge, Cambridge University Press, 1982)
9. *Examining the Complexity of Teaching*. Special issue of the *Journal of Mathematical Behavior*, **18**, 3 (1999).
10. *Issues in Education*, **4**, 1 (1998).
11. D. Hinsley, J. Hayes, & H. Simon, From words to equations: meaning and representation in algebra word problems. In *Cognitive processes in comprehension*, M. Just & P. Carpenter, Eds. (Hillsdale, NJ: Erlbaum, 1977), pp. 89-106.
12. Minsky, M. A framework for representing knowledge, in *The psychology of computer vision*, P. Winston, Ed. (New York: McGraw-Hill, 1977), pp. 170-195.
13. G. Leinhardt. On teaching, in *Advances in instructional psychology* (Vol. 4.), R. Glaser, Ed. (Hillsdale, NJ: Erlbaum, 1993), pp. 1-54.
14. R. Schank, & R. Abelson, *Scripts, plans, goals, and understanding*. (Hillsdale, NJ, Erlbaum, 1977).
15. G. PŪlya, *How to solve it*. (Princeton, Princeton University Press, 1945; 2nd edition, 1957).
16. R. Groner, M. Groner, M., & W. Bischof, Eds. *Methods of heuristics* (Hillsdale, NJ, Erlbaum, 1983).
17. Lampert, M. When the problem is not the problem and the solution is not the answer: Mathematical knowing and teaching. *American Educational Research Journal*, **27**, 1, pp. 29-63 (1990).
18. D. Zimmerlin & M. Nelson. The detailed analysis of a beginning teacher carrying out a traditional lesson. *Journal of Mathematical Behavior*, **18**, 3, 263-280. (2000).
19. A. Schoenfeld, Toward a theory of teaching-in-context. *Issues in Education*, **4**, 1, pp. 1-94. (1998)
20. A. Schoenfeld, J. Minstrell, Jim, & E. van Zee. The detailed analysis of an established teacher carrying out a non-traditional lesson. *Journal of Mathematical Behavior*, **18**, 3, 281-325. (2000).
21. A. Schoenfeld, A highly interactive discourse structure, in J. Brophy, Ed., *Social Constructivist Teaching: Its Affordances and Constraints* (Volume 9 of the series *Advances in Research on Teaching*) (New York, Elsevier, 2002), pp. 131-170.
22. A. Schoenfeld. On Modeling Teachers' In-The-Moment Decision-Making, in A. Schoenfeld, Ed., *A study of teaching: Multiple lenses, multiple views*. (A volume in the *Journal for research in Mathematics Education* monograph series). (Reston, VA, National Council of Teachers of Mathematics, in press.)
23. A. Arcavi & A. Schoenfeld. Using the Unfamiliar to Problematize the Familiar. In *Tendências Internacionais em FormaÁao de Profeso-res de Matem-tica (International Trends in Teacher Preparation)*, M. Borba, Ed. (Sao Paulo, Brazil, AutÍntica, 2006), pp. 87-111.

