Adaptive Expertise as Knowledge Building in Science Teachers' Problem Solving

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Abstract

Research on expert/expert differences has lead to a differentiation of adaptive expertise and routine expertise. Adaptive expertise was investigated as a knowledge-building orientation to problem solving in high school science teachers' instructional problem solving. An authentic task was administered to adaptive and routine experts as well as novices. Adaptive experts were found to show a higher orientation to knowledge-building during problem solving than routine experts.

Adaptive Expertise

Across many professions and domains of expertise, research has documented that self-directed, effortful problem solving in the context of everyday practice enables practitioners to learn and develop expertise (Chi, Glaser, & Farr, 1988; Eraut, 1994; Ericsson, 1996). Not all veteran practitioners attain excellence or become innovative in their practice. Increasingly, *adaptive expertise* is a construct used to explain the different developmental trajectories leading to excellence versus mere efficiency in problem solving (Hatano & Inagaki, 1986; Patel, Glaser & Arocha, 2000; Schwartz, Bransford, & Sears, 2005) as well as the superior performance of some experts over other experts (Raufaste, Eyerolle, & Marine, 1998; Wineburg, 1998).

The concept of adaptive expertise is rooted in findings from expert/expert studies, from which the contrast of adaptive experts and routine expertise arose (e.g., Bereiter & Scardamalia, 1993; Feltovich, Spiro, & Coulson, 1997; Gott, Hall, Pokorny, Dibble & Glaser, 1992; Hatano & Inagaki, 1986; Raufaste et al., 1998; Wineburg, 1998) . Among various distinguishing characteristics noted by experts, a key distinction is that *routine* experts excel in the application of skill and knowledge to familiar problems, and *adaptive* experts are able to *construct new knowledge* as they solve problems, are more accurate in problem solving, and handle new problems more successfully. During problem solving, the cognitive processes of adaptive experts are distinguished by a greater attention to available evidence; closer analysis of data; a dialectical working back and forth from data to knowledge base; and deliberate, explicit thinking-through of questions posed to the self and conclusions. It is likely through these cognitive processes that adaptive experts *build* their existing knowledge base rather than merely apply it (Chi, 2006; Feltovich et al., 1997; Raufaste et al., 1998; Wineburg, 1998).

Adaptive Expertise in the Practice of Teaching

Adaptive expertise has been described in a range of practices and contexts, including medical diagnosis (Feltovich et al., 1997; Patel et al., 2000), analysis of historical texts (Wineburg, 1998), business management (Barnett & Koslowski, 2002), and avionics device troubleshooting (Gott et al., 1992). Similarly, theoretical accounts of teacher learning and the development of teaching expertise have drawn the distinction between learning processes that make teaching more efficient or routine and those that lead to the progressive development of what has been termed flexible, transferable, or adaptive expertise (Ball & Bass, 2000; Bereiter & Scardamalia, 1993; Darling-Hammond & Bransford, 2005; Hatano & Inagaki, 1986; Wineburg, 1998). Not every problem of daily practice requires *adaptive* expertise to be solved adequately, but the processes of adaptive expertise are thought to enable professionals to build greater knowledge and skill through their practice—to *learn more* from experience (Bereiter & Scardamalia, 1993; Feltovich et al., 1997; Gott et al., 1992).

Adaptive expertise entails learning through problem-solving as opposed to simply applying knowledge and familiar heuristics to problems. Informal learning through practice of this nature is increasingly recognized as important in teachers' professional growth (Ball & Cohen, 1999; Bereiter & Scardamalia, 1993). Research has shown that instructional decision-making, lesson planning, and other aspects of teachers' everyday practice can be important loci for the development of expertise (Ball & Cohen, 1999; Shulman, 1986). Yet not all teachers learn and build expertise through practice in the same way or progress to the same level of expertise.

The aim of this theory-elaboration study was elaborate an analytical description of adaptive expertise in teaching. With this, one can understand how adaptive expertise contributes to teachers' development, link characteristics of adaptive practice to instructional performance, construct reliable measures of adaptiveness in instructional practice, and develop interventions that foster adaptive expertise. I do not view adaptiveness as a fixed or intrinsic attribute of individuals, but rather as a set of cognitive, metacognitive, social, and affective strategies and dispositions triggered in particular situations that merit abandonment of routine problem-solving strategies in favor of a learning-oriented approach to problem solving. Nor is adaptiveness viewed as characteristic of experts alone. Adaptiveness can occur, and can contribute to the development of expertise, at any point in a teacher's professional trajectory (Crawford & Brophy, 2006; Hatano & Oura, 2003).

The analysis reported in this paper stems from a larger study that used a laboratory-based research protocol to develop a theoretical description of adaptive expertise in a key aspect of teaching: instructional decision making. The goal of the analysis was to determine how veteran biology teachers with routine and adaptive profiles, as well as novice teachers, differ in their knowledge-building orientation in an instructional decision-making task that we devised.

The objective of this study was to examine expert/expert differences in problem solving orientation. Adaptive expertise entails a propensity to see problems as an opportunity for constructing new knowledge, rather than just applying existing knowledge, so that knowledge is more likely to be constructed through problem solving. This is akin to "general expertise" (Wineburg, 1998) that enables successful application of knowledge to moderately novel domains. With adaptive expertise, a knowledge-building orientation is balanced with considerations of efficiency and the use of efficient heuristics in problem solving (Schwartz, Bransford, & Sears, 2005). We examined differences between adaptive and routine experts in knowledge building during problem solving.

Hypotheses

Knowledge-building and detailed examination of empirical evidence are described in the literature as characteristics of adaptive expertise in problem solving (Bereiter & Scardamalia, 1993; Feltovich et al., 1997; Hatano & Inagaki, 1986; Wineburg, 1998), and as core characteristics of effective teacher learning (Ball, 2003; Ball & Bass, 2000; Ball & Cohen, 1999). For example, Ball and her colleagues have described analysis of student work and errors as fertile ground for the development of teachers' pedagogical content knowledge and knowledge of students. Thus, thoughtful analysis of student work has great potential to develop teachers' skill in instructional diagnosis.

To validate our theoretical framework, which views these characteristics of adaptive expertise as applicable to instructional diagnosis and decision making in high school science teachers, we examined the occurrence of knowledge building and use of evidence in problem solving among the high school biology teachers in our study who were selected to represent three profiles: adaptive veterans, routine veterans, and novices (two of whom we identified as having strong potential to show adaptiveness). The coding and analysis were intended to test several hypotheses. Some hypotheses relate to differences between adaptive veterans and routine veterans; other hypotheses relate to differences between veterans as a group and novices.

Regarding knowledge-building and efficiency in problem solving, we hypothesized the following:

1. Teachers identified *a priori* as adaptive veterans will show a greater proportion of knowledge-building utterances (text units) than routine veterans.
2. Veterans as a group will show a higher proportion of efficiency utterances (text units) than novices, who, we speculated, are likely not yet to have mastered the analytical heuristics that support efficient problem solving.
3. Novice teachers will show a higher proportion of knowledge building overall than both groups of veteran teachers. We reasoned that because novice teachers have less relevant knowledge (e.g., pedagogical content expertise; knowledge of students; curriculum knowledge), they would spend more time constructing knowledge through the task than would veteran teachers.

Research Design and Methods

An authentic instructional problem-solving task was administered to research participants, using a think-aloud approach. Our study protocol was a variation of the traditional laboratory-based problem-solving task used in the study of expert-novice problem solving (Chi, Glaser, & Farr, 1988; Ericsson & Simon, 1993; Ericsson & Smith, 1991; Gott et al., 1992). We adapted the method in several ways to approximate the complexity of an authentic instructional decision-making task in high school biology teaching.

Participant Recruitment and Selection

We sought to recruit high school biology teachers whose backgrounds and other characteristics conformed to one of three profiles: routine veteran teacher (we defined veteran as 7 or more years teaching high school biology), adaptive veteran teacher, and novice teacher (we defined novice as 2 or 3 years' teaching high school biology). We selected participants through questionnaires on their background, experience, professional activities, and beliefs; in some cases, we also used professional recommendations from local experts and two of the researchers involved in the study.

Criteria for the adaptive expert profile were derived from the literature on adaptive expertise and from approaches used in other studies of adaptiveness in problem solving, primarily Barnett and Koslowski (2002), Gott et al. (1992), and Wineburg (1998). Specifically, we sought individuals with some advanced training in education theory and/or research methods, or with a prior career that involved rich experience with problem solving and/or research. The rationale was that teachers with this profile would be likely to address problem solving in a more flexible, hypothesis-testing way, would evince a knowledge-building orientation, and would show less concern for efficiency in problem solving. Candidates with 7 or more years of experience teaching biology, but having none of the background criteria listed above, were considered routine veterans. We selected novice teachers who had come to teaching from another career that involved some form of research, hypothesizing that such experience might confer Wineburg's "general expertise" (Wineburg, 1998) or a form of problem-solving expertise that would be applied in our instructional reasoning task.

Thirteen high school biology teachers participated (all names used in this article are pseudonyms). Nine were veteran and four were novice teachers (2 to 3 years of experience). Based on the background information we collected at the time of recruitment, four of the nine veteran teachers were categorized as belonging to the "adaptive" profile and five to the "routine" profile, before they performed on our laboratory-based task. Two of the 4 novices selected had come to teaching from another career that involved some form of research. All participants but one were current high school biology teachers.

Instructional Decision-Making Task

The task and all accompanying materials were developed in consultation with a master high school biology teacher and a nationally recognized expert on genetics teaching and learning. Study participants were presented with a scenario in which the participant is taking over a 10^{th}-grade biology class of 22 students for a teacher going on maternity leave. The fictional class has almost completed a 5-week genetics unit (encompassing Mendelian genetics, DNA, genes, and protein synthesis). The main task statement for the participant reads: "Your task is to understand, as best you can, what your students have and have not learned in the genetics unit so far." To accomplish the task, the following task materials were available to the teacher participant:

- A set of 22 student scored practice tests and the practice test answer key.
- The class grade book (a printout from a grade book software program) containing information about students' cumulative course points, homework points.
- A table summarizing individual students' scores on each practice test question, along with average points scored on each item and average practice test scores. This artifact was given participants on request or after participants had examined the student practice tests for 10 minutes, whichever came first.
- The genetics unit lesson plans, including many activity materials, handouts, and assignments, and the course textbook.
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The task was extensively pilot-tested with biology teachers and science teacher educators with biology backgrounds, and refined through several iterations throughout the pilot-testing process. Participants and experts in teacher learning deemed the task authentically representative of tasks that teachers perform in their practice.

Embedded Features of the Task Structure. The design of the practice test questions and the design of the student responses on multiple-choice and constructed-response items embedded patterns of correct and incorrect responses, which indicated misconceptions well researched in the literature on genetics learning (Heim, 1999; Stewart 1982; 1983). Two patterns of erroneous responses indicated specific student misconceptions in genetics: one on genetics reasoning (reasoning from effect (phenotype) to cause (genotype) and cause to effect), the other related to concept of dominance of an allele. We embedded these patterns to provide opportunities for teachers to engage in instructional diagnosis and to trigger episodes of reasoning in which teachers could display adaptive constructs (e.g., forward and backward reasoning processes; knowledge-constructive analysis of the case materials) during problem solving.

Procedures

Informed consent was obtained. Participants were trained in the think-aloud process, using standard training procedures (Ericsson & Simon, 1993). After the think-aloud training, participants were reminded that their task was to determine what students had learned from the unit so far, and they were encouraged to ask the experimenter for any information or artifacts they felt they needed, in addition to those in front of them.

The task was administered in two phases: The first phase, the "initial scenario," had participants perform the task with minimum interruptions from the experimenter (other than reminding them to continue to think aloud, and providing them with the spreadsheet on request or after 10 minutes of examining student tests). This phase ended when the participant indicated that he or she had completed the task of determining what students had learned from the unit so far. The second phase, "prompt administration," was initiated immediately after the participant had completed the task on his or her own. The experimenter gave conditional prompts to orient the participant to examine (or re-examine) key parts of the materials to determine whether prompting to examine task materials more closely would help the participant to discern data patterns not detected in their "initial phase."

Upon completion of the prompt section, a cognitive interview was conducted with the participant to clarify, where necessary, participants' strategies and thinking during and resulting from the first two phases of the task. Finally, the participant was debriefed about the research study. The whole session, including the think-aloud training, took up to 2 hours, and was audio- and video-recorded.

Data Coding and Analysis

Coding of Verbal Protocols. The resulting think-aloud protocols were transcribed verbatim. Transcripts were prepared to indicate length of pauses and were annotated, based on the videotape, with information on the research participant's use of the task materials. The primary unit of analysis for the transcribed text was a *text unit* of the verbal protocol transcript. Adapting Gee's (1996) approach to the treatment of transcribed text for discourse analysis, we defined a "text unit" as a complete idea, including main clause, any subordinate clauses, and any associated false starts, (Gee, 1996). Utterances that were participants' reading of text contained in the task materials were group the specific text unit related to the that material.

The transcripts were coded for *task orientation.* Task orientation was coded in terms of two mutually exclusive categories: *knowledge-building* and *efficiency*. Our goal with task orientation coding was to capture "meta" statements that indicate participants' orientation to the task at a given moment. We want to identify where the participant was opening up the problem space (indicating a knowledge-building orientation) and where the participant was closing down or reducing the problem space, for example, to finish up the task (indicating an efficiency-orientation). We assumed that all participants would exhibit some degree of both of these, and that some participants would show an orientation to the task that privileged one over the other, and that some participants would show a balance of the two.

This analysis examined the degree to which participants demonstrated an effortful attempt to construct knowledge related to analysis of the data to draw conclusions, and the degree to which participants attempted to simplify the task, think about the effective use of time while doing the task, and finish up the task. We defined ***knowledge-building orientation*** as ways that participants approached the task such that she or he is oriented to "opening up" the problem space and exploring the available artifacts in the service of sense-making and knowledge construction. We used a single code to capture this orientation. Types of utterances coded as "knowledge-building" included:

- Questions or statements to self about what one would like to know or to find out. Example: "I wonder how pedigree is taught."
- Drawing conclusions based on examination of the artifacts
- Examination of artifacts
- Indications of interest, curiosity. Example: "I am curious why students did not get this."
- Metacognitive or self-regulative statements about the participant's own knowledge state or understanding with respect to understanding what students know and don't know. Example: "Okay, I have some idea about what students know"; "As I look at this, I am a little confused about student thinking."

Excluded were utterances that indicated an *intention* to find out something for the purpose of planning a lesson for the remaining days before the final test, or completing the task. Example: "I think I am done with the task, but let me double-check the task scenario."

An ***efficiency orientation*** was defined as involving simplification of the task or the problem space, monitoring time spent on or remaining for the task, considering trade-offs in time required to accomplish a sub-goal versus time available or value of the results, and thinking about what remained to do to finish the task. In our pilot-testing, we noted that nearly all teachers spend time describing how they would approach instruction related to topic, and nearly all teachers did planning related to how the last one or more lessons would be implemented to help the students learn content identified as still needing to learn. Such lesson planning was categorized as efficiency because all teachers felt that this was the last step of the task, to plan the lesson; piloting showed us that many teachers "rushed" into lesson planning to complete the task, foreclosing on analysis of data. Thus, lesson planning was identified as an orientation to task completion rather than problem or data exploration or sense making.

Two researchers were trained with this coding scheme, coded half of one transcript and compared the coding results. The reliability for both the efficiency code and the knowledge-building code was above .95. The researchers discussed the disagreements and refined the decision rules, and recoded the disagreements. After this reliability was established, all the transcripts were single-coded by one the analyst. Questionable cases were flagged in the course of coding, discussed by the two analysts, and resolved.

Findings and Discussion

For this analysis, we examined only participants' performance in the initial task scenario (the participants' initial completion of the task, prior to the experimenters' prompts to the participants to examine or re-examine specific aspects of the task). We compared groups (adaptive veteran, routine veteran, and novice) on the mean percentages of text units coded as knowledge building and efficiency. As expected, routine and adaptive veterans were highly similar in the proportion of *efficiency-oriented* utterances they displayed (adaptive-veteran mean = 11.52%; routine-veteran profile = 13.55%) (see Figure 1). However, the two groups differ markedly in knowledge-building orientation exhibited during the task. The adaptive-veteran group had a mean of 17.37% of all text units coded as knowledge building, whereas the routine-veteran group showed a mean of only 7.68% of all text units. Novices were similar to the adaptive-veteran group, with a mean of 16.35%.

Next experience-level groups (veteran and novice) were compared on knowledge building and efficiency. As expected, the veteran teachers as a group and the novice teachers differed markedly in their degree of efficiency demonstrated during the completion of the task. Novices showed much less orientation to efficiency in their completion of the task. Veteran teachers had a mean of 12.65% text units coded as related to efficiency in task performance, whereas novice teachers had a mean of 2.6% of text units coded as related to efficiency. Although the samples are very small, this difference is statistically significant at the .05 probability level. ($t = 2.34$; df = 11, $p = .039$). The novice teachers also showed somewhat more knowledge building during the initial task than the veterans as a group. Veterans had a mean of 12% of all text units coded as knowledge building; novices as a group had a mean of 16.36%. The difference is not statistically significant.

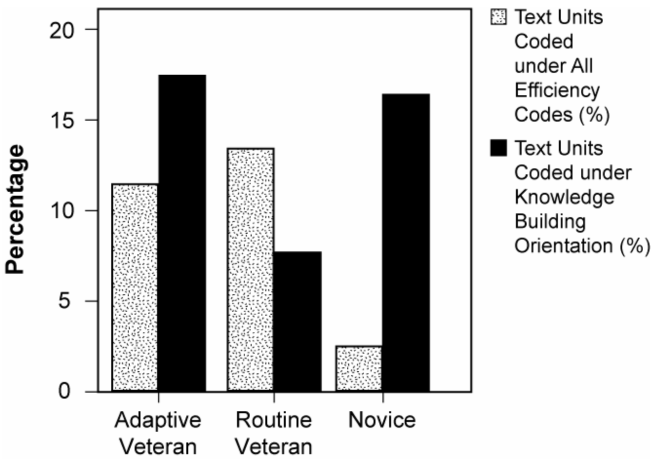

Figure 1. Mean percentage of efficiency and knowledge-building text units, by profile.

We speculate that novice teachers' comparative lack of efficiency during problem solving reflected that they had yet to develop the efficient heuristics and routines associated with expertise coping with domain-specific problem. The level of knowledge building displayed by novices, which was about equal to that of adaptive veterans, is difficult to interpret. Their sense-making efforts could reflect their relatively lower levels of domain knowledge. Alternatively, because we purposely selected novices who had previously engaged professional in some form conceptual problem solving, these novices may have been exhibited adaptiveness in problem solving. A general-knowledge task would be required to disentangle knowledge from adaptiveness. Indeed, such a line of research is critical to further elaborating the construct of adaptive expertise (Crawford & Brophy, 2006).

The finding that adaptive and routine veterans exhibited equal amounts of efficiency during problem solving supports Schwartz, Bransford and Sears's (2005) formulation of adaptive expertise as an optimal balance of innovation (or knowledge building, in my terms) and efficiency in problem solving (see Figure 2). Adaptive and routine experts differed only in the level of knowledge building they exhibited, not in the level of efficiency. Adaptive experts were as efficient in problem solving as routine experts, but they explored the task more deeply.

Overall, adaptive experts created a more complex functional problem space for themselves than did routine experts. Qualitative analysis of utterances coded as knowledge building indicated that adaptive veterans differed most from routine veterans in the nature of their high-level sense-making during analysis of student understandings as exhibited on the test. Adaptive veterans closely analyzed the test questions to better interpret the student responses; routine veterans almost never analyzed the test questions. Adaptive veterans much more frequently posed questions or wondered to themselves about many of their observations, directing their review of the materials to answer these various questions. In sharp contrast, the routine veterans took a satisficing approach to the task; generating a simple list of "topics to review" seem to be the functional task for most routine veterans.

This analysis of knowledge building and efficiency in problem solving demonstrated that as postulated, teachers tended to show three basic patterns or orientations in the approach the task: and tendency toward knowledge building with a lack of efficiency in the process (the novice profile); a tendency toward extreme efficiency at the expense of knowledge building through the task (the routine-veteran profile); or a balance of knowledge building with efficiency (the adaptive-veteran profile). In addition to these three predicted patterns, some participants showed low levels of both variables such that an overriding pattern or tendency could not be discerned.

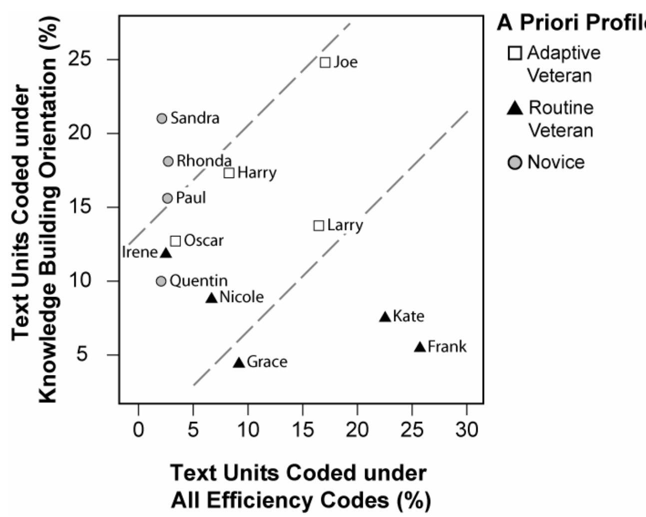

Figure 2. Knowledge building plotted against efficiency in problem solving: Adaptiveness as optimal balance of the two dimensions.

We maintain that adaptiveness can be exhibited at any time in the development of a teacher's practice. I further view adaptiveness not as an intrinsic trait but as a set of cognitive and self-regulative skills and abilities, as well as habits of mind and dispositions. Adaptiveness in our theoretical framework comprises dispositions and habits of mind that enable one to jump out of the ruts of habit (highly automated heuristics), set aside routines, and selectively give up efficiency in order to "go deep"—and to recognize and pursue the promising problems that reward "going deep." Doing so creates rich opportunities for knowledge building and innovation of new procedures. In addition, adaptiveness requires proficiency with some skills and abilities, such as specific problem-solving heuristics, so that one is not unable to sort out minutiae to discern the important patterns in a set of data, unable to formulate worthwhile overarching goals for the analysis, or unable to identify, develop, and pursue a productive line of analysis to arrive at a solution or understanding of a problem.

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