REPORT ON A LABORATORY STUDY OF TEACHER REASONING

Characterizing Adaptive Expertise in Science Teaching

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Introduction and Overview

Project MAESTRo (Measuring Adaptive Expertise in Teachers' Reasoning) is a 3-year study designed to characterize and measure adaptive reasoning and decision making processes in high school biology teachers' analysis of student work, both individually and in collaboration. Our dual aim is to advance research on adaptive expertise as a central construct for understanding the socio-cognitive bases of teaching expertise and teacher learning through practice.

The three major goals of the project, each addressed in a separate sub-study, are to:

- Define and document cognitive processes that are characteristic of adaptive expertise in biology teachers' instructional reasoning about students' content knowledge and understand their relationship to performance in problem solving (Year 1 study);
- Characterize processes of adaptive expertise in the social context of professional collaboration among science teachers (Year 2 study);
- Develop a self-report instrument that validly and reliably measures teachers' propensity to exhibit adaptiveness in their instructional practices (Year 3 study).

Our goal in this project is to apply the concept of adaptive expertise to science teaching in order to understand what benefits adaptiveness confers to teachers' learning, development, and performance. In addition, we hope to contribute to the effort to refine and clarify the construct of adaptive expertise and understand how it contributes to learning and performance in general. Our long-range goal is to enable STEM education researchers, teacher education faculty, and professional development providers to design research-based learning experiences for teachers that foster adaptive expertise and promote excellence in science teaching. The basic research described in this paper establishes a theoretical foundation for later controlled experimental studies investigating the relationship between adaptive expertise and instructional effectiveness and for the development of teacher education and professional development interventions.

In our first study, we developed a laboratory task that asks high school biology teachers to examine student grade book information, test data, and student work related to a five-week genetics unit in order to diagnose student understandings. The task is designed to elicit two aspects of adaptive expertise documented in the literature: (1) adaptive reasoning processes and problem solving heuristics (Feltovich et al., 1997); and (2) adaptive orientations to learning in the context of problem solving (Wineburg, 1998). The task is administered with a variant of the standard think-aloud protocol method used in cognitive studies of problem solving (Ericsson & Simon, 1993).

This paper begins with a review of the literature on adaptive expertise in relation to problem solving and reasoning in teaching. We describe the research base that underpins our theoretical framework and informs the design of our laboratory task and analytical approaches. Next, we describe the design and procedures of the laboratory task and our analytical methods. Finally, we present preliminary findings from the analysis of transcribed verbal protocols of teacher participants performing the laboratory task.

Adaptive Expertise and Teaching

Adaptive expertise, as it has been elaborated in the literatures on expertise, problem-solving, and learning, is a broad construct that encompasses a range cognitive, motivational, and identity or personality-related components, as well as habits of mind and dispositions. In this section, we review the construct of adaptive expertise and literature that documents the various benefits that adaptive expertise has been shown to confer, including innovativeness, flexibility in problem solving, and learning through problem solving. We conclude by presenting our own analytical framework for investigating adaptive expertise in teachers' reasoning.

Our own research focuses on cognitive and metacognitive processes and professional dispositions that can enable teachers to *extend* their knowledge and skill when instructional diagnosis and decision making demand more than simply applying existing knowledge and procedures. We identified a subset of the varied aspects of adaptive expertise as most relevant to instructional decision-making, focus of our study and most relevant to knowledge construction, as opposed to knowledge application.

This focus on processes that enhance the *construction* of knowledge through problem solving rather than simply the *application* of knowledge aligns with our goal of understanding how adaptiveness can support teachers' learning and development as they address the everyday problems of teaching. Through our research in this area, we are beginning to elaborate the construct of adaptive expertise in teaching in terms of adaptive practice. *Adaptive practice* refers instructional practice that is a site of knowledge construction. It is characterized by a stance toward knowledge-building rather than maximizing efficiency in such as way that productive problems and opportunities for knowledge construction are overlooked, removed, or avoided. We describe the concept of adaptive practice more completely elsewhere (Crawford, et al., 2005).

In elaborating the construct of adaptive expertise in the domain of teaching, we connect the literature on adaptive expertise to the literature on teaching and teacher reasoning. Thus, our work builds on Shulman's (1986, 1987) theory and research on the knowledge base for teaching; on Ball and Cohen's (1999) work on teachers' learning through everyday practice; on Ball's (e.g., Ball & Bass, 2000) recent work on pedagogical content knowledge and teachers' reasoning; and on the argument that diagnosis is the cornerstone of the practice of teaching (Hinds, 2002; Solomon & Morocco, 1999).

Adaptive Expertise and Routine Expertise

More than two decades of research on expertise has documented a set of general characteristics of expertise and differences between the performances of experts and novices across many domains of knowledge, skill, and practice. Among the hallmarks of expert performance are the following: (1) experts notice features and meaningful patterns of information that are not noticed by novices; (2) experts can retrieve from memory relevant knowledge quickly and with little attentional effort; (3) experts tend toward routinization and automaticity in their performance, which increases speed and efficiency; and (4) experts have rich, complex domain-specific knowledge schemas, constructed from large amounts of experience, that are differentiated and hierarchically integrated (Bransford et al., 2000, Chi, Glaser, & Farr, 1988).

Research has also documented the limitations of expert performance, some of which can be traced to the same attributes of expertise that, in most situations, lead to superior performance over non-experts. For example, under certain conditions, some experts exhibit a *reductive bias*—a tendency to view situations or problems as simpler than they really are—leading to misconceptions and inferior performance, such as misdiagnosis of medical disorders or lack of creativity (Feltovich et al., 1993, 1997). Other studies have found that although all experts are able to solve familiar types of problems quickly and accurately, some have only modest capabilities in dealing with novel types of problems (Holyoak, 1991). In addition, research has noted that while some experts focus on *applying* knowledge and procedures to address new cases and solve problems, other experts are more apt to use new cases or problem as opportunities to learn and extent their knowledge (Bereiter & Scardemalia, 1993; Hatano & Inagaki, 1986; Schwartz, Bransford, & Sears, 2005).

Such findings have led to a field of study on the differences between "routine" expertise and "adaptive" expertise (Hatano & Inagaki, 1986) and on the characteristics and benefits of adaptive expertise. Understanding the distinctions between routine and adaptive problem solving and reasoning has important implications for learners as well as experts, because adaptiveness enhances learning through problem solving. Therefore, researchers have begun to focus on adaptive expertise as an important cognitive capacity to understand and promote in an increasingly complex, knowledge-intensive, and fast-changing world (Bransford et al., 2000).

Adaptive Expertise Research

A distinguishing characteristic of adaptive expertise is the ability to apply knowledge effectively to novel problems or atypical cases in a domain without glossing over distinctive features or factors. Adaptiveness allows experts to recognize when rules and principles that generally govern their performance do not apply to problems or situations (Gott et al., 1992). Moreover, studies have shown that this flexibility can result in better performance than that of experts who do not display cognitive flexibility, resulting in more accurate medical diagnosis (Feltovich et al., 1997), better technical trouble shooting (Gott, et al., 1992), and workplace error avoidance (Woods, Johannesen, Cook, & Sarter, 1994). Holyoak (1991) characterized adaptive experts as capable of drawing on their knowledge to *invent* new procedures for solving unique or novel problems, rather than simply applying already-mastered procedures. This flexible, innovative application of knowledge in unique cases in large part underlies adaptive experts' greater tendency to *enrich* and *refine* their knowledge structures on the basis of continuing experience–to learn from problem-solving episodes (Bransford, et al., 2000; Feltovich et al., 1997; Gott et al., 1992; Hatano & Inagaki, 1986).

Bransford et al. (2000) cite studies by Hatano and Inagaki (1986), Miller (1978), and Wineburg (1998) that show how the reasoning and problem solving approaches of routine and adaptive expertise differ. Hatano and Inagaki (1986) argue that some individuals, in solving a large number of problems, learn merely to perform a skill faster and more accurately, without constructing or enriching their conceptual knowledge. Such individuals are sometime called expert, because their procedural skills are highly effective for solving everyday problems in a stable environment. While they are outstanding in speed, accuracy, and automaticity, they lack flexibility and adaptability to new problems. Rather than simply applying their knowledge to solve a task expeditiously, some experts see a task as an opportunity (or as requiring them) to depart from the routine and expand their expertise. Those experts engage in an effortful and time-consuming– but valuable–process of reflecting on their goals and the limits of their knowledge, reframing a problem in light of contradictory evidence, and entertaining alternative solutions. Bransford et al. (2000) conclude that "Adaptive experts are able to approach a new situation flexibly and to learn throughout their lifetimes. They … are metacognitive and continually question their current levels of expertise and attempt to move beyond them" (p. 48).

Beyond characterizing the differences between adaptive and routine expertise, researchers have characterized reasoning and problem-solving *processes* that enable adaptive experts to continue to learn. One such process is theory-building or explanation-testing (Bereiter & Scardamalia, 1993; Gott et al., 1992; Hatano & Inagaki, 1986). Rather than *assuming* that their current knowledge and their problem definition are correct, adaptive experts draw on their knowledge in light of situational factors or unique aspects of a case to formulate a *possible* explanation or a *theory* of the situation which they test in the given context of the problem at hand. Holding this epistemic distance between their knowledge and problem representation on the one hand and the empirical evidence or situational particulars on the other hand allows adaptive experts to apply knowledge to cases more accurately; to produce more adequate solutions; and to expand their knowledge, for example by incorporating information about how it does and does not apply in specific cases. The notion of characteristically adaptive cognitive *processes* is critically important because it suggests that adaptive practices can be exhibited *at any level or stage of expertise development*. In other words, the concept of adaptive expertise is productive in understanding learning at all developmental stages—in childhood, beginning professional practice, and expert practice (Feltovich et al., 1997; Gott et al., 1992; Spiro, Feltovich, Jacobson, & Coulson, 1991).

Thus, research on adaptive expertise demonstrates that the skills, knowledge, and dispositions comprised by adaptive problem solving and adaptive practice plays an important role in fostering learning and the development of expertise and excellence. Thus we believe that the concept of *adaptive expertise* holds great promise in understanding the professional development of teachers and how to promote learning and the development of expertise through practice. The notion of adaptive expertise can help us gain analytical purchase on the habits of mind, forms of knowledge, and skills that enable some teachers to engage in continuous learning through practice and to "take more" more from experience as they develop and refine expertise, improve their instructional practice, and help their students develop adaptive learning processes. A theory of teacher learning that addresses adaptive expertise is necessary because tools, practices, domain content, and the characteristics of learners are no longer static over the course a teaching professional's career. Teachers must learn continuously in order to handle this complex, rapidly changing learning environment. Teachers in the 21st century, in order to become and remain effective, need to *innovate* new solutions and approaches as new tools become available, and contexts and needs change. Thus, a theory of teacher learning should begin from a view of teaching as encompassing *practice*, *learning*, and *innovation*.

Framing Adaptive Expertise for the Current Study

Our theoretical framework for studying adaptive expertise in teachers comprises two main components: 1) characteristics of the teacher as knower; and 2) cognitive and metacognitive processes brought to bear when engaging complex problems of practice. Our review of the literature suggests that several prerequisite metacognitive stances as well as the deployment of specific cognitive processes in problem solving are critical in characterizing how teachers construct knowledge and innovate new methods, strategies, and procedures through reasoning about everyday tasks and problems.

Table 1. Aspects of Adaptive Expertise.

Epistemic and Dispositional Aspects of Adaptiveness	Adaptive Cognitive and Metacognitive Processes
▪ Maintain an epistemic distance between prior knowledge and model of a case or problem at hand ▪ An epistemic stance that views the world as complex, messy, irregular, dynamic, etc. ▪ Comfort or willingness to reveal and work at the limits of one's knowledge and skill ▪ An inclination toward learning rather than merely applying knowledge	▪ Data-oriented forward reasoning (hypothesis-based reasoning) ▪ Causal reasoning ▪ Seeking and analyzing feedback about problem-solving processes and outcomes ▪ Monitoring results and performance ▪ Monitoring own learning ▪ Assessing own knowledge states ▪ Assessing adequacy of current knowledge for solving case at hand

The specific dispositions, skills, and processes that we address within each of these components are summarized in Table 1. First, adaptive reasoning and problem solving involves maintaining an epistemic distance between knowledge and problem representation on the one hand and empirical evidence (or data) on the other hand (Hatano & Inagaki, 1986; Wineberg, 1998). That is, the problem solver does not assume that her current knowledge or problem representation is necessarily adequate to the case at hand. Instead, she holds her problem-framing lightly and is thus able to reframe the problem as new information emerges and is able to recognize where her current knowledge may not be adequate to the case at hand.

When an individual maintains *epistemic distance* between the evidence and prior knowledge, it is more likely she will be able to make adjustments and corrections in one or the other, as the two are coordinated and integrated dialectically in the process of problem solving. We theorize that this epistemic distance between the knowledge brought to bear and the representation of the case at hand contributes to greater accuracy in building a cognitive representation of the situation and to correctly applying prior knowledge to the case at hand.

Second, *case sensitivity* is required. That is, the individual must be alert to the particulars of a given problem, case, or a set of data. This requires that the individual adopt an epistemic stance that does not assume that a given case will be the same as prior similar cases. It also requires that the individual does not assume that one's prior knowledge is adequate the problem at hand, allowing the unique elements and requirements of the problem at hand to be recognized by the teacher.

Third, the individual must have the *metacognitive skills* to recognize where her current domain knowledge is not adequate for the present problem and must have a professional disposition to risk revealing that she does not know something (Hodges, Brophy, & Brandford, in preparation). Similarly, individual also must have a disposition to treat the problem at hand as an opportunity to learn.

Beyond these prerequisites, adaptive reasoning involves cognitive processes and heuristics in *exploration* of all relevant data without dismissing or foreclosing on any relevant evidence, to construct a correct working model or diagnosis of the case (Gott et al., 1992; Feltovitch et al., 1993; Patel & Groen, 1986). Exploration of data with the use of forward reasoning strategies has been demonstrated to lead to more correct analysis of evidence (Patel & Groen, 1986).

Given our focus on problem solving and reasoning processes in teachers' analysis of student work to diagnose misconceptions, we identified in the adaptive expertise literature four forms or characteristics of reasoning and problem solving that are characteristic of adaptive expertise in problem solving:

- **Data-Driven Forward Reasoning:** Reasoning characterized by a string of observations and tentative hypotheses which are tested against data before a conclusion is reached. Conclusions may be revised as more data is collected and analyzed (Patel & Groen, 1986; Wineberg, 1998).
- **Causal Reasoning:** Formulates a specific model underlying the problem or a deep functional representation of the causal components of the problem space (Gott et al. 1992; Hatano & Inagaki, 1986).
- **Cognitive Flexibility:** Considers multiple possible hypotheses, diagnosis or problem framing. Attends to data that do not fit prior knowledge or typical explanation. Changes problem solving strategy in light of new information; formulates tentative or possible conclusions in the course of problem solving. (Feltovitch et al., 1993, 1997)
- **Self Regulation:** Makes explicit evaluative or self-regulative comments about one's own problem-solving process. Shows self-awareness of progress or lack of knowledge (Bereiter & Scardamalia, 1993).

The epistemic and metacognitive stances and reasoning processes described above are characteristic of an "adaptive" orientation to problem solving. Adaptiveness in problem solving entails an *orientation toward knowledge construction* or *theory*-building in problem solving. This orientation contrasts with what we call an *efficiency orientation* to problem solving. Whereas an adaptive orientation involves tendency toward *optimizing* (note we do not say "maximizing") a given case or problem as a learning opportunity, an efficiency orientation involves a tendency toward satisficing, for example, by exploring the case just thoroughly enough to "get the job done" or to quickly make a reasoned judgment.

An efficiency orientation often entails discounting data that do not fit with a hypothesis and approaching the case or problem with strong assumptions and prior knowledge that are not checked for appropriateness or adequacy against the data at hand. Bereiter and Scardamalia (1993) characterize this as the "best fit" approach to problem solving, in which the problem-solver looks for a fit between the case at hand and their prior experience, thereby foreclosing on detection of a difference between their past experience or prior knowledge and the case at hand. The "best fit" approach to problem solving prevents the individual from discerning and hence *learning* something new in the case at hand. Drawing on the cognitive psychology literature in medical diagnosis, Bereiter and Scardamalia contrast the best fit approach with a *theory building* approach, in which the problem solver tries to build a theory that explains all aspects of the case, rather than leaving out or discounting the unfamiliar or anomalous.

In their recent work, John Branford, Dan Schwartz, and their colleagues present a compelling and useful model that articulates the mutually enabling and constraining relationship between innovation (very closely related to our notion of adaptiveness) and efficiency (Schwartz, Bransford, & Sears, 2005). They characterize innovation and efficiency as two dimensions of learning (and transfer), represented on x- and y-axes, that are in tension with each other but that mutually constraining and enabling of each other and of problem solving. In this model, there is a corridor through the center of the conceptual space defined by the x- and y-axes that defines "optimal adaptability." Both adaptiveness and efficiency are necessary in problem solving – too much of either would have a negative effect on problem solving. The two must be balanced appropriately for the problem at hand. Part of adaptiveness is being good at judging what the right balance is for a given problem. Some problems may require more innovation; other contexts may either require efficiency or offer little reward for innovation or adaptiveness.

Bereiter and Scardamalia (1993) provide a longitudinally oriented analysis of the complementary relationship between efficiency and innovation in the trajectory of gaining expertise in teaching. In their account, gains in efficiency in the practice of teaching free up a teacher's time and energy. Teachers who are on a trajectory toward building expertise reinvest gains in time and energy into addressing increasingly complex problems within their teaching practice. This does not mean systematically hunting down all problems and puzzles with the aim of eliminating them but rather reformulating the everyday problems of practice in progressively complex terms, thereby gaining greater knowledge and improving practice over time.

In sum, an efficiency orientation is characterize by rapidly drawing conclusions based on limited exploration of the case, typically out of a concern to move on to other tasks or out of a lack of concern with building new knowledge or learning from the case at hand. By contrast, an adaptive orientation to problem solving is characterized by thorough, systematic exploration of data, the use of reasoning strategies that effective in reviewing data and formulating hypotheses (forward reasoning, causal reasoning, and self-regulation), tentativeness in drawing conclusions about case, formulating and testing hypotheses against the data, and being willing to open to finding out one's knowledge is not adequate to the case at hand. It is also characterized by interest, curiosity, anticipation about novelty or unfamiliar content within a case or set of data.

We emphasize that adaptiveness and efficiency are not characteristics of individuals but rather orientations that are exhibited or not exhibited in a given context. Teaching is a highly demanding, high-performance profession in which teachers must rapidly make many decisions in a highly complex and time-pressured conditions (Carter et al., 1987; Cypher & Willower, 1984; McDaniel-Hine & Willower 1988). Efficiency is extremely important in such a practice. However, to build expertise, it is also important to be able and inclined to "jump the tracks" of routine and efficiency when appropriate, to be alert to novelty, nuance, and to seek out interesting problems, and to apply the abilities, dispositions, and skills that enable one to learn through tackling the ordinary–and extraordinary–problems of practice. Exhibiting adaptiveness is not only dependent on a set of dispositions and skills problem-solving processes but also on the situation and the problem at hand. Some problems should trigger adaptiveness more than others. In our view, adaptive expertise entails the metacognitive skills to recognize which problems will reward the effortful process of adaptive problem solving – and when it is time to "just get it done".

Empirical Study of Adaptive Expertise in Science Teachers' Reasoning Processes

Our overarching goal in studying adaptive expertise is to better understand the underlying mechanisms – the skills, dispositions, and abilities – that place some teachers on a trajectory toward the development of expertise and excellence through learning in the course of everyday practice, rather than a trajectory of simply becoming ever more efficient at teaching. That is, we want to understand how teachers acquire a flexible form of expertise through tackling the everyday problems of teaching in a way that promotes knowledge construction and innovation.

The purpose of Year 1 of our project is to develop an analytical vocabulary for describing adaptive and efficiency orientations in teachers' reasoning. It is not our goal to identify adaptive or efficient teachers, but rather to identify and characterize episodes or sequences of adaptive and efficient orientations in teachers' reasoning as they analyze student work and perform instructional decision making. In addition, we want to understand how adaptive and efficiency orientations in problem solving correlate with results of the reasoning and problem solving process, that is, correct or incorrect diagnosis of student understandings, detection of patterns in student work and data on student learning. To achieve this goal, we devised our first study of adaptive expertise in high school biology teachers' reasoning using a laboratory-based teaching task administered to teachers in a 2-hour session. The task that we ask teachers to perform focuses on one of the core practices of teaching: analysis of student work to diagnose student understandings. We carefully designed this task to elicit two forms adaptiveness: adaptive reasoning processes and adaptive response (learning) to unfamiliar content in the course of problem solving. The effectiveness of the laboratory task and its ecological validity were ascertained through extensive pilot testing.

Rationale for Methodology

Why Biology Teachers? Biology is a field in which scientific knowledge has advanced at an extremely rapid pace in the last two decades. Life science teachers today need to be adaptive experts in order to keep abreast of rapid advances in the field of bioscience. Indeed, the biosciences have become increasing differentiated and continue to proliferate into more subfields (e.g., biophysics, bioinformatics, bioengineering) (Hurd, 1997). Life science teachers also need to continuously learn and incorporate new knowledge into their pedagogical strategies. Many high school biology curricula require teachers to incorporate biotechnology wet labs and simulation software tools into their instruction. Teachers need to have the habits of mind and problem-solving strategies that enable them to incorporate new knowledge, strategies, and tools for teaching life science in ways that foster improved achievement as well as better understanding of their students' learning processes.

Why a Cognitive Task? The study uses a laboratory-based cognitive task analysis methodology. Teacher participants work through a realistic task that asks them to analyze student work to diagnose student understandings based on a four-week unit on genetics, thinking aloud as they work. Cognitive analysis of task performance, conducted on a transcription of the participant's think-aloud protocol during the task, is the method most commonly used in cognitive studies of reasoning (e.g., Chi, Glaser, & Farr, 1988; Ericsson & Charness, 1994; Ericsson & Smith, 1991; Gott et al., 1992). This method allows the researcher to observe and analyze the participant's strategies and reasoning processes in a cognitively complex task.

Three criticisms have been leveled at this approach: One is that thinking aloud interferes with task performance. However, interference effects have been studied and generally found to be minimal (Ericsson & Smith 1993). Another criticism is that a think aloud protocol cannot be validly treated as "window" into the participant's cognitive processes but should rather be treated as discursive performance that is co-constructed by the task design. We agree that the data in the form of a think-aloud protocol of a participant's task performance is, like all data, co-constructed by the participant and the data collection instruments and methods (Crawford & Valsiner, in press). Our stance toward the verbal data, consistent with the method of cognitive task analysis, is that it represents an accurate and reliable representation of the cognitive processes involved in solving problems in the task (Ericsson, 1992; see also Ginsberg, 1997).

A third criticism of this approach is that a laboratory-based study lacks ecological validity; therefore findings regarding reasoning processes in a laboratory task may or may not transfer to performance of reasoning tasks in actual job performance. Our laboratory task certainly constrains the problem space that teachers are asked to address and eliminates some of the complexity of the types and circumstances of reasoning tasks that teachers' perform in their real-world contexts. This was necessary in order to construct a manageable corpora of data for intensive cognitive analysis.

To gauge the authenticity of our task–the degree to which our task represents the types of reasoning tasks teachers actually perform in their jobs–we asked our teacher-research participants to rate the task along several dimensions, after they had performed the task and been paid. We found that teachers' viewed the task as very authentic and realistic, as compared with the kinds of tasks they perform everyday. Their responses are summarized in Table 2.

Table 2. Research Participants' Ratings of Task Authenticity.

	Average Rating
To what degree did you enjoy this task? (be honest!)	3.75
To what extent was the **thinking and analysis you did on this task** similar to the kinds of thinking and analysis you do in your teaching job?	4.00
How realistic were the **materials** you looked at for this task (student tests, lesson plan, etc.)?	4.13
How realistic was the **task scenario**? (That you were replacing a teacher out on maternity leave and needed to review student work in order to take over the class)	4.38

N = 9. Scale: 1 = Not at all; 2 = Slightly; 3 = Moderately; 4 = Very; 5 = Greatly.

Research Methods

Task Scenario: The teacher-participant is presented with the scenario that he or she is taking over a 10th Grade Biology class of 22 students for a teacher going on maternity leave. In the task scenario, the class has almost completed a five-week Genetics Unit (encompassing Mendelian genetics and protein synthesis). The main task statement for the teacher 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 are given to the teacher participant:

- A set of 22 student practice tests completed a week before the final genetics unit test. The test includes 26 multiple choice items and five open-ended questions. The test papers are corrected and scored. A test key is also presented. The test is designed to cover content from the entire genetics unit.
- A spreadsheet summary of individual students' performance on each practice test item.
- The class gradebook, unit lesson plans, and textbook.

The task and all materials included in it were designed, developed, and tested by researchers working in consultation with a master high school biology teacher and an expert on genetics teaching and learning. The task was then extensively pilot tested with biology teachers and teacher educators with biology backgrounds, and went through numerous iterations and revisions throughout the pilot testing process.

Task Design: Designed into the task are some data patterns (patterns of incorrect and correct students answers to certain practice test items and patterns of test performance data) that indicate student misconceptions. These embedded patterns provide the researchers with a way of evaluating the thoroughness and results of the participant's analysis of the task materials. The misconceptions to embed were selected based on the literature on genetics learning (Heim, 1991; Steward, 1982, 1983; Steward, et al. 1990).

One pattern of data indicates that students have a misconception regarding the concept of dominance of an allele and believe, incorrectly, that prevalence of a trait in a family or population indicates that the trait is dominant. (The pattern of student responses on the question in Figure 1, below, provide data relevant to this misconception.)

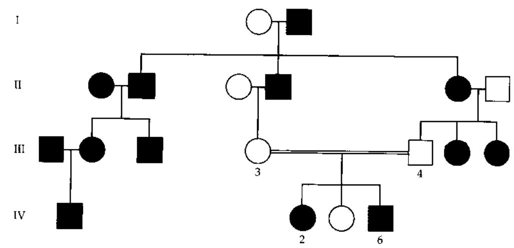
Another pattern of data indicates that students have difficulty reasoning from effect (phenotype) to cause (genotype). This pattern of students' difficulty occurs across six different multiple choice items. (One example of question providing evidence of this misconception is Question 11, presented in Figure 1.)

The task embeds also an opportunity for the research participant to learn novel content in the process of diagnosing student understandings. A recent and important scientific finding in DNA research, non-ribosomal peptide synthesis (that is, proteins assembled by a system other than the ribosomes), is embedded in the lesson plans and practice test. Most biology teachers are not familiar with this finding and therefore would have difficulty assessing students' answers to the test question that asks about this new finding and its implications. To be successful, the teacher participants need to learn something about the novel content themselves, which they can do through either reading student answers or the lesson plan materials.

Figure 1. Sample Questions from Practice Test Included in Task Materials.

(Correct answers are in boldface type.)

2. A ferret breeder has been keeping a pedigree for four generations of a ferret family. The pedigree indicates which members of a family of ferrets exhibit a kinked tail (black shapes) and which members do not (white shapes). Select the option below that indicates the correct trait inheritance pattern and associated explanation for this pedigree diagram.



Key:
Black shape indicates affected individual (trait expressed);
white shape indicates unaffected individual (trait not expressed).
Circle indicates female; square indicates male.

a. Dominant, because every generation of the family expresses the trait.
b. Recessive, because individuals 3 and 4 don't express the trait, but 2 and 6 do.
c. Dominant, because most of the individuals in the family express the trait.
d. Cannot be determined because of insufficient information.

11. Tim and Jan both have freckles (a dominant trait), but their son Michael does not. If Tim and Jan have another child, what is the probability that he/she will have freckles?

a. 1/4 b. 3/8 c. 1/2 **d. 3/4**

Task Administration: Prior to the task administration, informed consent is obtained from the research participant, and the participant is given a gift certificate for a nationwide retail store as payment for their participation (payment is $100, with an extra $50 paid to teachers who live more than 20 miles away from research study location). Study goals are described to the participant in the following way:

> "The purpose of this study is to explore biology teachers' instructional decision making. We have absolutely no interest in or guesses about 'right;' or 'wrong' approaches to this task. Our goal is only to describe and understand biology teachers' reasoning processes. That's why we'd like you to think aloud as you do this task. … As mentioned in the consent form, I am going to ask you to engage in a task that involves a hypothetical scenario related to biology teaching. The task is designed to be challenging for novice and experienced teachers alike. I want to assure you that we are not assessing you; your performance on this task in no way reflects on you as a teacher. I am simply interested in what you are thinking as you perform the task."

Participants are then trained in the think-aloud process, using standard training procedures (Ericsson, 1992).

The task is administered in three phases: First, the participants performs the task with minimum interruptions from the experimenter. This phase is entirely open-ended, allowing the teacher participants to frame the problem, plot a path through the task materials, and engage her or his prior knowledge, heuristics, and strategies to perform the task. The participants may or may not detect the embedded data patterns in this phase. After the participant completes the task, in the second phase, the experimenter gives dynamic, conditional prompts to orient the participant to examine (or re-examine) key parts of the materials, in order to determine whether, when prompted to examine task materials more closely, the participant is able to discern data patterns and novel content not discerned in their "first pass" through the task. Finally, a cognitive interview is performed in the third phase in order to clarify, where necessary, the participants' strategies and thinking during and resulting from the first two phases of the task.

The whole session including the think-aloud training takes up to 2 hours, and is audio- and video-taped. The resulting think-aloud protocols are transcribed verbatim and annotated with information regarding the research participant's use of the task materials.

Research Participants and Recruitment: Participants are experienced (7 or more years of experience) or novice (2–3 years of experience) high school biology teachers. Several science teacher educators with classroom teaching experience were also invited for the piloting of the task. Verbal protocols have been collected from both highly experienced teachers and novice teachers so that we eliminate the influence of a strong knowledge base or teaching experience on their reasoning processes and task performance.

To find teachers who are likely to exhibit adaptive orientations in our task, we initially aimed to recruit research participants primarily with extensive K–12 teaching experience as well as indicators of an orientation toward continuous learning and the development of expertise. We used a combination of indicators to identify these teachers, including the following characteristics: advanced training in educational theory and practice or advanced scientific training, exemplary participation in instructional reform initiatives, and performance of instructional leadership roles. We reasoned that teachers with extensive teaching experience, advanced knowledge, and continuous learning and leadership are likely to exhibit adaptive expertise in performing our laboratory task.

To recruit teacher participants, we asked teacher education professionals to nominate outstanding teachers. The nominated teachers were contacted and asked to complete a questionnaire about their professional experience background. Teachers identified as likely to exhibit adaptiveness, based on their questionnaire responses, were invited to participate in the study. We also recruited through snowball sampling, asking teachers who complete the task to nominate colleagues whom they thought would excel at our task.

We also recruited teachers who were thought not to be likely to exhibit adaptive expertise on the task. These teachers were identified either through confidential nomination by a colleague of ours who had worked with them or through absence of the indicators named above, determined through completion of a questionnaire. Finally, novice teachers were recruited through recommendation by a colleague leading a novice teacher mentoring program.

At the time of writing, we have 11 experienced teachers and 1 novice teacher have participated in the study (excluding pilot test participants). We plan to recruit a few more experienced teachers and several more novice teachers to participate in the study.

Data Analysis

The purposes of the analysis are to 1) describe adaptive reasoning and problem solving processes teachers exhibited completing the task, (2) discern contrasts between an adaptive orientation and an efficiency orientation to problem solving, and (3) correlate adaptive or efficiency reasoning with performance in correctly or incorrectly diagnosing student understandings. Two main analyses of the verbal protocols are performed. First, all protocols are rated for the performance on (a) the degree of detection of data patterns on student misconceptions (about the concept of dominance and effect-to-cause reasoning), (b) detection and response to novel genetics content in the materials, and (c) the extent to which the participants interact with the task materials to examine student understandings. Second, the extent and nature of adaptive and efficiency orientations are analyzed through careful examinations of the protocols. Details of these two analyses as well as an additional analysis to synthesize the results from the two are presented below.

Analysis of Task Performance: We developed rubrics to evaluate the extent to which the participant identified the embedded patterns of two main student misconceptions as well as to evaluate the participant's response to the novel content. For the effect-to-cause reasoning misconception, the rubric captures whether the participant differentiates that students do well on items requiring cause-to-effect reasoning (making inferences about the phenotypes of offspring based information about the parental genotypes) but have difficulty with effect-to-cause (phenotype-to-parental genotype) reasoning. For the misconception about the concept of dominance, the rubric rates teachers on their detection that many students chose a wrong response option (C) and that this option is diagnostic of a common student misconception—that is if a trait is prevalent in a population (or family), the allele for that trait is dominant.

With respect to participants' response to novel content, the rubrics evaluate the extent to which the participant acknowledges unfamiliarity with novel content, the extent to which she or he seeks to learn the novel content in order to analyze students' test answers, and the correctness of the participant's understanding of the novel content.

Finally, another rubric characterizes the extent of the participant's engagement with the available data in examining student work.

Analysis of Adaptiveness and Efficiency in Reasoning Processes: We found that the traditional approach to protocol analysis performed in cognitive analysis of tasks (see Ericsson, 1992) was not appropriate for the protocols resulting from our task, because the problem space of our task is much more complex and ill-structured than tasks typically used in cognitive analysis. The verbal protocols from our task were also much more varied than is typically documented in the literature. Therefore, a microanalytical textual analysis (cf. Ginsberg, 1997) of participants' reasoning processes is conducted in order to asses the extent and nature of adaptiveness in the verbal protocols. These analyses are currently being performed on our corpora of verbal protocols, more of which are being collected.

First, we analyze the verbal protocol for the occurrence of the following three types of adaptive reasoning processes: data-oriented forward reasoning,causal reasoning, and cognitive flexibility. Next, we examine the occurrence of an efficiency orientation in the verbal protocols. Efficiency is indicated by three characteristics in the verbal protocol: (1) the absence of the three types of adaptive reasoning processes describe above, (2) prevalence and timing of *decision-oriented statements*, that is, statements about the subsequent phase of instructional decision making, usually lesson planning, and (3) a limited degree of examination of the available data. Our preliminary analysis indicated that some teachers perform only limited and brief analysis of student work and then go on to lesson planning and making other decisions based on this limited analysis of student work. These teachers foreclose on a fuller analysis of the available materials and usually do not detect the embedded design of the task or notice the novel content. Thus, the prevalence of decision-oriented statements, such as lesson planning, and decision-confirming (as opposed to hypothesis testing) statements, are indicators of an efficiency orientation in problem solving.

Synthesizing Analysis: Finally, the analysis of performance (the rubric ratings) and the adaptive expertise analysis are correlated in order to understand what benefits adaptiveness in reasoning confers to performance. In addition, episodes of efficiency orientation are contrasted with episodes of adaptiveness for the same component of the task in order to develop a set of contrasting comparisons of adaptiveness and efficiency. The goal of this comparison is to refine our characterization of these two types of orientations in teachers' reasoning. Finally, episodes of adaptive reasoning in the protocols of experienced teachers will be compared with episodes of adaptive reasoning in the protocols of novice teachers (if any are found to occur in protocols from novices) to better understand the role that prior knowledge plays in task performance and reasoning processes.

Preliminary Findings

Verbal protocols of task completion are still being collected (June 2005), and analyses are performed as the protocols are prepared. Nine highly experienced high school biology teachers have participated in the study so far. (Seven other teachers were part of the piloting process to develop the analytical strategies.) Preliminary analyses have been performed on the nine protocols.

All participants showed indications of biology teaching expertise though knowledge of content, pedagogy, and assessment strategies. Our preliminary findings suggest that:

1. Our task is effective in eliciting contrasting approaches to reasoning and problem solving: adaptive processes and efficiency-oriented processes. However, performance on the task overall and particularly in detecting and interpreting the embedded patterns has been highly variable. In some cases, the occurrence of adaptive reasoning processes within a specific "area" of the task space does not co-occur with detection of the patterns of student understandings designed into that area of the task. That is, adaptive behaviors do not necessarily lead to identification and interpretation of the embedded patterns of evidence.

2. Adaptive processes, in the form of data-driven forward reasoning, causal reasoning, and cognitive flexibility, are exhibited in some verbal protocols and that these

processes co-occur with more indepth and systematic exploration of the task materials and data on student understandings.

3. In protocols where an efficiency-orientation is prevalent during the initial task performance (that is, participant's initial, uninterrupted pass through the task with only the open-ended task scenario guiding their problem-framing and analytical approach), efficiency is also more prevalent than adaptiveness in the prompted section of the task performance (when participants are prompted to re-examine specific portions of the data on student understandings). The reverse is also true; in protocols where, for example, data-driven forward reasoning is exhibited during the initial task, it is also exhibited in the prompted section of the protocol.

4. The two distinct forms of adaptive expertise we are investigating, adaptive reasoning processes and in orientation to novel content, co-occur in the verbal protocols. In protocols where adaptive reasoning processes are prevalent, a learning-response to novelty is also observed. Likewise, in protocols where an efficiency orientation is prevalent, typically no learning response to novel content is evident. This preliminary finding supports the view that adaptiveness in reasoning is supported by a set of more general habits of mind, dispositions, and an epistemic stance that likewise underpin other forms of adaptiveness, such as tendency toward learning (rather than avoidance or non-learning) in response to novelty.

Finally, our analysis of adaptiveness and efficiency in research participants' approach to the task seems to be successful in detecting and characterizing a consistent and robust pattern of contrasting processes and dispositions in protocols from different teachers. The specific characteristics of these contrasting approaches are summarized in Table 3.

Table 3. Characteristics of Adaptive and Efficiency Orientations in Teacher Reasoning Task.

Adaptive Orientation	Efficiency (or Routine) Orientation
Slow to draw conclusions, building mental model of situation from evidence	Quick to draw conclusions from one aspect of the problem space
Thorough, systematic exploration of data	Limited, unsystematic exploration of data
Tentativeness, posing questions to self	Certainty, satisficing to complete the task
Test hypotheses and judgments against new data	Retain hypotheses based on prior knowledge
Build understanding of situation through data	Interpret situation in terms of prior experience, assumptions
Explicit statements about not-knowing novel conetnt	No statements about not-knowing novel content
Explicit testing of model with nonconfirming information	Avoidance or discounting of nonconfirming information
Shows interest, curiosity about novel content	Shows no interest in novel content

Discussion and Examples of Response to Novelty

In this section, we present a few sample excerpts from the verbal protocols that exemplify the research participants' engagement with the task materials.

Example 1. Brenda's Learning Response to Novel Content

In this example, a research participant, Brenda (all names are pseudonyms) is prompted to re-examine the materials in the task that embed the novel content. She did not discern the novel content during her initial problem solving in the task, and is therefore prompted by the experimenter to re-examine the relevant materials. ("T" indicates the teacher-participant and E indicates the experimenter administering the task. Line numbering is continuous throughout the verbal protocol.)

477. E: Okay let's move on, actually move backwards now to question 31. If you can take another look at question 31 to determine what it indicates about what students do or do not understand about this topic. So and actually looking at what their answers indicate about what they do or do not understand about this problem.
478. T: Alright .
479. Okay. [Reading part of Q31] Now that we have a complete list of all the genes for these organisms we can figure out all the proteins that these organisms make and finally understand how these living things function. [Pause]
480. Okay well you know it's a multilevel question I am not sure how much they would have already studied the genome.
[. . .]
484. I didn't see anything that had to do with expression levels or .. in translation different types of controls on translation. [. . .]
486. It says here for human, yeast, and e. coli cells, list the structures that assemble proteins.
487. So the first part is ribosomes and the reason for that question would just be to.. if the kids understand that that process is pretty much the same in terms of using a ribosome for the messenger RNA.
[. . .]
489. E: Do you want to take a look maybe there's something under tab 19 [in the Lesson Plan notebook]. You could take a look at the materials that—something whether that sheds on any light on what the students' misunderstanding or understandings are related to this topic.
490. T: Okay, [reading materials in Lesson Plan] summarize how proteins are made, discuss the purpose of genome Projects and what they help to accomplish?
491. [Reading selected portions aloud] If you know every gene you know every protein but there are proteins that have no genes.
492. [Reading] Not all proteins are made by ribosomes.
493. [Reading] Students read articles from science and discuss answer questions on NRPS books students review [long pause]
494. Wow . that's cool. [pause]
495. E: What?
496. T: I had not heard about these .. these giant enzymes that recognize amino acids and link them directly into genes…
497. So is, do you mind if I read this or are you—?
498. E: Be my guest.

In line 494 Brenda expresses excitement about the novel content and a desire to become familiar with it. Then, in line 497, Brenda explicit requests time to read the article immediately. She also asked the experimenter whether a copy of the article was available to take. (Brenda was given a copy of it.)

Example 2. Dora's Learning Response to Novel Content

The next verbal protocol excerpt provides another example of a learning response to novel content. Like Brenda, this participant was prompted by the experimenter re-examine the task materials that embed the novel content. In this case, Dora explicitly states that she does not know the novel content (line 348) and then decides on her own that in order to interpret the student work that involves the novel content she must herself first find out what the novel content is by finding it in the task materials and reviewing it. This is a learning response to novelty.

344. E: Please take a look at student answers to question 31 to determine what they indicate our students understanding about this topic. [pause] I will just remind you that. [moves the textbook off the student tests]
345. T: Okay, I am going to take a minute here to read the question carefully [Q31]. [long pause] [. . .]
348. **I don't know what is meant by NRPS proteins** but I see that— [pause] hmm.
349. E: [reminds participant to think aloud.]
350. Yeast, and E. coli have NRPS and . . human cells don't [Q31A]. [pause]
351. I don't know what NRPS is.
352. And it says possible answer to B that there are no genes for NRPS proteins. [pause]
353. **Well, I need to see if I can find that in the book so I can better understand what the response is** . . [. . .]
358. Well, I can't find it in the text book .
359. So . ah ha! "Working outside the protein synthesis rules" [reading the title of the NRPS article]
360. Figure it had to be in one of these little articles that she had the students read.
361. Okay . this is from Science and I'm impressed that she is having them read something from Science, even if it is a short news article as opposed to a report.
362. And . Non-Ribosomal Peptide Synthetases [pause] ah ha! . . penicillin . . **Good. very up to date.** [pause] [reading, flipping through pages]
363. Okay [pause] well— . . [. . .]
373. **And I learned something new today, that's cool.** [laughs] [pause]

Example 3. Efficiency Response to Novel Content

Brenda's excited response to the materials contrasts with that of Charlie, who evinces an efficiency-orientation to the novel content, opting not to read the two brief articles provides. Instead, he immediately begins planning lessons and making other decision-oriented statements regarding the novel content based on an only superficial review of it.. In the excerpt, Charlie is prompted to review the materials relevant to the novel content embedded in the task. In line 555, Charlie indicates that he chooses not to read the novel materials. Then, after flipping through the Lesson Plan materials and gaining a cursory overview of them, he begins, in line 559, to make lesson planning and other decision-oriented statements. Planning and other decision-oriented statements are also overwhelmingly predominant in the initial task problem solving section of Charlie's verbal protocol, which we interpret as characteristic of an efficiency orientation.

541. E: Um hum. Okay. And now as a last part to that I would like you to review the materials in lesson plan notebook related to this topic, and that's under tab 19.
543. E: And see if that sheds further light on students' understanding related to this topic.
[. . .]
546. T: Okay, discuss the importance—okay, so you want – okay – [. . .]

548. T: And that's—okay [flipping pages of Lesson Plan Notebook] . . this is not my expertise, believe me.
549. Okay, [reading Objectives of Day 23 in Lesson Plan] discuss the importance of the whole genome project, and what they hope to accomplish. Explain how some important proteins are made without genes, and discuss the reasons and . reasons this is important, okay. [. . .]
552. [Reading] Discuss the purpose of the genome projects, and what they hope to accomplish [Part B of Day 23]. [. . .]
554. Okay, let's see, so here's an article on working outside the protein synthesis rule.
555. Okay . now lesson . . **now I'm not going to take time to read article but okay**. [. . .]
558. Non-ribosomal peptide synthesis—what it is, okay, okay . . [flipping pages of Lesson Plan Notebook]
559. **I'm just looking here to see if they wanted to go further, where they can go.**
[. . .]
563 And, I guess, I guess I . would ask myself, you know, is . is this question, which I believe is the only question related to this lesson, and if it is, what are the expected outcomes to teacher who wants, wanted the students to [?bring].
564. And, I think I would be inclined to include some questions for the student to answer relating to these articles that would . get at kinds of things that's reflected in this practice test . . [flipping pages]
565. **I would want to give the students some guidance.**
566. This is pretty text dense.
567. And from my experience, I know that some students are not gonna understand this unless it's broken down with some questions that gives them . some reinforcement of their understanding of what the article is saying.
568. **And so I definitely would want to do that.**
[. . .]
671. And I—I would want to—I can almost—sure that it's not in the textbook because the textbook can't keep up with all of the new stuff.
672. I'm sure it's not in the textbook.
673. If it is in the textbook I would piggyback on what's there.
674. But I would want to support these articles with some questions.
675. And I would definitely want to add some additional articles if their others that would be at a level of them I understand.

Notice that whereas Dora explicitly states she is not familiar with the novel content (characteristic of adaptiveness), Charlie does not indicate he is unfamiliar with it. Indeed he seems to keep up a pretense of knowing it and only in the cognitive interview portion of the task administration, when asked by the experimenter, states that he was not familiar with the content.

Summary

Teaching is a multifaceted and cognitively complex practice; adaptive expertise can be exhibited in nearly any aspect of teaching, depending on prior knowledge, situational factors, and the task at hand. Our goal is not to compare the performances of teachers who exhibited adaptiveness and those who did not and label those people as adaptive experts or not; rather our objective is to develop an analytical vocabulary for describing adaptive expertise, in contrast to an efficiency orientation, in teachers' problem solving in the analysis of student work.

In the initial phase of our research we chose to investigate adaptive aspects of expertise in one specific teaching task: Diagnosis of students' understandings or thinking based on analysis of student work. We took this as our focus for two reasons: (1) Teaching is increasingly viewed as a clinical profession, requiring acute discernment and judgment, excellent problem-solving skills, continuous learning from unique cases, and the integration of many domains of knowledge to effectively address problems (Ball & Bass 2000; Hinds, 2002; Solomon & Morocco, 1999); (2) This aspect of instructional practice can be profitably addressed through research on adaptive expertise, which emphasizes understanding how knowledge and reasoning processes are brought to bear on complex problems in specific domains such that individuals do not merely solve problems but also frame problems in progressively complex ways to promote learning from solving problems (Bereiter & Scardamalia, 1993; Feltovich et al., 1997; Gott et al., 1992).

The aim of our first study was to characterize the reasoning processes involved analysis of student work and determine whether we could find evidence that adaptive strategies and dispositions (a) enable teachers to more accurately diagnose student understandings, and (b) motivate teachers to learn novel content in the course of problem solving.

We designed a laboratory task that has proved to be effective in eliciting efficiency and adaptive orientations in teachers performing task. Our preliminary findings indicate that adaptiveness in the form of data-driven forward reasoning, causal reasoning, and cognitive flexibility are exhibited in some verbal protocols and that these processes are correlated with greater and more systematic exploration of the task materials and data on student understandings. We are finding that where adaptiveness is exhibited in verbal protocols, the research participant is slow to draw conclusions, building mental model of situation from evidence; thorough relatively systematic in exploration of data; shows tentativeness in drawing conclusions and poses questions to herself; builds understanding of task materials and through data, rather than through an over-reliance on or imposition of prior knowledge; and show interest, curiosity, anticipation about novel content and a disposition to learn about it.

Promoting excellence in science education requires that we understand and promote the development of teacher expertise in teacher education, professional development, and retention efforts. We need to better understand the ongoing and highly interwoven cognitive (Shavelson & Stern, 1981), metacognitive processes, dispositions, and skills in the context of practice (Ball & Cohent, 1999) that result in excellent teaching and improved student outcomes. We need to understand how to launch teachers effectively on a trajectory of professional development that builds toward a flexible form of expertise that enables teachers to readily incorporate new findings in science into their curriculum, to implement new pedagogical techniques from the learning sciences into their teaching, to effectively assess what students know and can do, and to model for their students the learning strategies and dispositions that will prepare students to be problem solvers and continuous learners in- and outside the classroom.

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