SYMPOSIUM REPORT

ADAPTIVE EXPERTISE: THEORY, METHODS, FINDINGS, AND EMERGING ISSUES, SEPTEMBER 2006

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Symposium Goals and Overview

Investigations of adaptive expertise are informing learning scientists' theories of instruction, assessment, and teacher professional development. The goal of the Adaptive Expertise Symposium was to collectively describe the conceptual territory being charted by current studies of adaptive expertise, examine the constructs and methodologies that are used in those studies, discuss the investigation of adaptive expertise in informal and formal learning contexts, and consider directions of future research.

The Adaptive Expertise Symposium was held at SRI International (SRI) on September 22 and 23, 2005, and brought together more than 30 researchers and graduate students to share and critique current theoretical frameworks and methodology in the study of adaptive expertise. The symposium began with presentations on empirical research and findings. Participants then discussed their conceptualizations of adaptive expertise, methods of investigation, and modes and strategies of analysis in their research on adaptive expertise. Leading expertise researchers, Drs. Marlene (Micki) Chi, Vimla L. Patel, and Harold Nelson, participated as "consulting experts."

The symposium was highly interactive, with lengthy Q&A sessions after each presentation; extended whole-group discussions; and extended, interactive small-group discussions related to key objectives of the symposium: conceptualization, methods, and research questions. The symposium is intended to be the first in a series of meetings of affiliates with LIFE, VaNTH, SRI, and other research organizations to discuss the development of the concept of adaptive expertise and its relation to learning and instruction in formal and informal settings.

This report begins with an overview of adaptive expertise to provide background for the reader. Next, we provide brief summaries of the presentations made at the symposium, as well as a brief synopsis of key symposium activities. Then, because small-group and whole-group discussions were a major focus of the symposium, we provide summaries of the key topics and themes from those discussions. Next, we provide a summary of the comments and reflections provided by our three consulting experts during a panel session on the second day. Drawing on the discussions, we offer our own critical reflections on key issues that emerged from the symposium. In the final sections of the report, we present a discussion of next steps, symposium evaluation results, and a list of symposium participants. A bibliography of adaptive expertise is appended to the report.

Background: Adaptive Expertise and Its Emergence in Research on Learning and Expertise

The symposium's exploration of the development of adaptive expertise built on the seminal work of the late Giyoo Hatano and his colleagues (e.g., Hatano & Inagaki, 1986; Hatano & Ouro, 2003) who differentiated "adaptive experts" from "routine experts." Hatano and Inagaki (1986) studied abacus experts who could perform prodigious feats of mental arithmetic by running "abacus simulations" in their minds. Their abilities seemed to defy well-established constraints on the limited capacity of working memory.

The feats of these experts were highly constrained to particular stimuli (e.g., numbers but not words) and to particular conditions (e.g., no distractions). The experts were content to stay within their limited areas of abacus-based expertise rather than attempting to expand, for example, to attempt mathematical calculations that were more complex than arithmetic. Hatano and his colleagues called them "routine experts." By limiting themselves to particular settings where demands remained relatively stable they developed procedural knowledge, which as Hatano noted, is often efficient but only for limited types of problems.

Hatano and colleagues also identified "adaptive experts," who contrast with "routine experts" in key ways. Adaptive experts continually expand their expertise, sometimes in ways that prompt them to restructure their understanding. Hatano and colleagues suggested that the development of adaptive expertise is driven in part by variability in people's environments (e.g., people who learn to farm in greenhouses where climate and soil conditions are kept constant, versus those who farm "in the wild" and continually face new challenges—weather conditions, soil depletion, competition from other farmers using tools such as tractors that increase productivity). Hatano also conjectured that personal characteristics such as "curiosity" play important roles in moving beyond routine expertise.

Research on adaptive expertise has built heavily on the expertise literature (e.g., Chi, Glaser, & Farr, 1988; National Research Council [NRC], 2000). For the most part, the literature on expertise has compared the performance of experts with that of novices. *How people learn* (NRC, 2000) and in Chi (2006a) summarize a number of features of expertise, which include:

- Detection and recognition of meaningful and important patterns and features.
- Self-monitoring for error detection and comprehension.
- Knowledge structured in terms of "big ideas" and meaningful connections among concepts.
- Use of appropriate and effective strategies in problem solving.

In addition to establishing key differences among experts and novices in regard to problem solving and performance, research on expertise in a variety of domains has demonstrated important differences in experts through expert/expert studies. Some experts, for example, have a *reductive bias*—a tendency to view situations or problems as simpler than they really are—leading occasionally to misconceptions and inferior performance, such as misdiagnosis of medical disorders or lack of creativity (Feltovich, Spiro, & Coulson, 1993, 1997). Expert performance is domain-limited, and experts often gloss over details (Chi, 2006a).

These studies have been helpful in uncovering various pitfalls and liabilities that may be associated with expertise. This research has also pointed to important differences among experts: (1) some individuals simply *apply* knowledge to situations or problems, whereas others continuously *learn* from their application of knowledge to problems; (2) some individuals perform successfully only with routine problems or situations, whereas others can successfully adapt their knowledge to novel or more complex problems or situations. Adaptive expertise research is animated by a concern for understanding the nature of these differences, the characteristics that contribute to them, and the role of instruction in promoting them.

For example, Wineburg's expert/expert study of historians (1998) elaborated on ideas of expertise and adaptability. Wineburg explored the application of what he called "general expertise" in a domain—which is similar to adaptive expertise and contrasts with specific expertise—in solving a domain-specific problem. An adaptive expert addressing a topic outside his area of expertise in his domain (which was history) engaged in a metacognitive, effortful process of interpretation, with a dialectical interpretive process that enabled him to *learn* in the process of problem solving, rather than simply applying familiar procedures and schemata.

Researchers have begun to use the concept of *adaptive expertise* as a way of articulating the importance of people's capacity to understand and perform in an increasingly complex and fast-changing world (NRC, 2000). Among the distinguishing characteristics of adaptive experts are metacognitive and self-regulatory strategies that enable them to recognize nuances in problems and the limitations of their knowledge for new types of problems, and the ability to apply knowledge effectively to novel problems or atypical cases in their domain without glossing over distinctive features or factors. Adaptive experts can recognize when rules and principles that generally govern their performance do not apply to problems or situations (Gott, Hall, Pokorny, Dibble, & Glaser, 1992). Studies have shown that this flexibility can result in better performance than that of routine experts, such as more accurate medical diagnosis (Feltovich et al., 1997; Patel & Kaufman, 1995), better technical trouble shooting (Gott et al., 1992), and avoidance of workplace error (Woods, Johannesen, Cook, & Sarter, 1994).

Holyoak (1991) characterizes adaptive experts as being able to draw 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; that is, to learn from problem-solving episodes (Bereiter & Scardamalia, 1993; Feltovich et al., 1997; Gott et al., 1992; Hatano & Inagaki, 1986; NRC 2000).

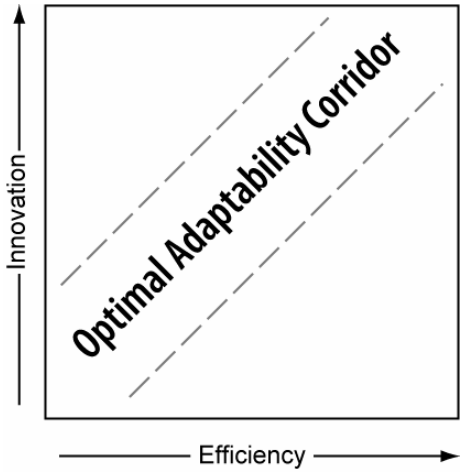
Adaptive expertise involves reasoning and problem-solving processes that enable experts to continue to learn and adapt to new situations. Adaptive expertise in problem solving is often characterized by theory-building, explanation-testing, self-questioning, and self-explanation (Bereiter & Scardamalia, 1993; Gott et al., 1992; Hatano & Inagaki, 1986; Wineburg, 1998). Whereas routine experts typically assume that their current knowledge and 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 that they then test in the given context of the unique problem. Adaptiveness involves keeping an epistemic distance between one's current knowledge and problem representation on the one hand and the empirical evidence or situational particulars on the other. This approach allows adaptive experts to apply knowledge to cases more accurately; to produce more adequate solutions; and to expand their knowledge through problem solving by, for example, incorporating information about how their current schemata do and do not apply in specific cases.

The NRC (2000) report cites 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. Rather than simply applying their knowledge to solve a task expeditiously, some experts view a task as an opportunity (or a necessity) to depart from the routine and expand their expertise. These 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, and entertaining alternative solutions. The NRC (2000) authors state 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). It is important to note, however, that these kinds of adaptive behaviors are often not elicited in typical "sequestered problem-solving" settings where people have no access to resources other than their own memories. Different views of assessment and transfer are needed to study many kinds of adaptation, what some have called "preparation for future learning" views (e.g., Bransford & Schwartz, 1999; Schwartz, Bransford, & Sears, 2005).

Schwartz, Bransford, and Sears (2005) analyzed adaptive expertise in terms of two opposing but complementary dimensions: innovation and efficiency (see Figure 1). Efficiency represents the collection of knowledge and experiences

(schemas) experts leverage for solving routine problems fast and efficiently. The innovation skills represent the knowledge-building skills associated with expanding knowledge in pursuit of solutions to novel problems. These skills include not only the ability to identify this knowledge but also the willingness to break from the routine and explore others' perspectives. Doing so provides opportunities to identify improvements to old methods or to conceive of entirely new opportunities. This framework of efficiency counter-balanced with innovation provides a new way to talk about the interaction between previously mastered knowledge and skills on the one hand and continuous learning, development, and innovation on the other.

Figure 1. Optimal Adaptability Corridor.



Source: Schwartz et al., 2005.

Adaptive expertise researchers view adaptiveness as only loosely linked to expert-level knowledge. The problem-solving processes characteristic in adaptive expertise can be exhibited *at any level or stage of development*. The concept of adaptive expertise is productive in understanding all learning (Bereiter & Scardamalia, 1993; Feltovich et al., 1997; Gott et al., 1992; NRC, 2000). Spiro and his colleagues (e.g., Spiro, Feltovich, Jacobson, & Coulson, 1991; Feltovich et al., 1997; see also Patel, Glaser, & Arocha, 2000) hold that the processes of adaptive expertise can be "carried over to almost all learning and practice experiences" (Feltovich et al., 1997, p. 137). Bereiter and Scardamalia (1993) examine learning through practice and the acquisition of expertise in terms of *progressive problem solving*. In their view, flexible expertise both entails and results from two closely interrelated processes: (1) reinvestment of freed-up mental resources (resulting from efficiency gained through routinization acquired through extensive experience) in increased learning, and (2) tackling more complex forms of recurring problems. The second of these processes involves formulating problems at the highest possible level of complexity, which contrasts with taking either a "best fit" approach (i.e., problem definition in terms of current

knowledge schemas) or “problem reduction” (i.e., simplistic formations of problems).

Understanding adaptive expertise as an optimal balance between efficiency and innovativeness (Schwartz et al., 2005) provides a framework for approaching instruction and assessment in ways that promote adaptiveness. This framework also challenges the “skills first” or “general problem solving first” approach to instruction. The framework suggests that instruction that co-develops both efficiency and innovation constitutes an optimal developmental path for learning. This model for describing the interaction of key characteristics of expertise is being used by several of the researchers presenting at the symposium who have been trying to define scales for these dimensions (e.g., Barron, Bransford, Brophy, Crawford, Sears, Sivhla, Walker).

This review of adaptive expertise highlights important characteristics of expertise that should inform the goals of instruction and assessment. Typical assessment methods in schools are more likely to measure the efficiency dimension of expertise, and only do so in narrow contexts. Yet assessments are often used as indicators of students’ preparedness for future situations that will differ markedly from the context in which the assessed knowledge, skills, and abilities are initially learned and tested.

Key Symposium Formats and Activities

The goal of the first day of the symposium was to share and critically discuss symposium participants' current research related to adaptive expertise. The goals of the second day were to engage in deeper critical analysis of the constructs, theories, assumptions, and research methods discussed in the presentations and the small-group discussions; and to discuss promising directions for future research. Over the course of the 2 days, a spiraling discussion unfolded, as participants considered various conceptualizations and operationalizations of adaptive expertise in different domains, and returned to a collective consideration of the construct of adaptive expertise. Particular concerns in the discussions included distinguishing adaptive expertise from routine expertise, characterizing innovation and the relationship of innovation to adaptive expertise, and defining approaches for investigating adaptive expertise that recognized its developmental nature.

Presentations of Research on Adaptive Expertise

The first day featured presentations of current research projects on adaptive expertise. Eight presentations were made. This section provides brief summaries of each presentation.

John Bransford, LIFE/University of Washington
Framing Comments: Conceptualizing Adaptive Expertise

Dr. Bransford argued that the idea of "adaptive expertise" provides a useful "gold standard" for rethinking the skills, knowledge, and attitudes necessary for the fast-changing world in the 21st century. Some aspects of adaptive experts involve the acquisition of schemas and routines that support efficient processing. However, people also frequently have to "unlearn" and "let go" of cherished ideas and practices, and doing so can generate fear, anxiety, and other strong emotions. The idea of adaptive expertise also requires new ways to think about transfer and assessment. Typical theories of transfer involve the application of previously learned schemas, and typical tests assess efficiency in problem solving. Broader theories of transfer ask how previous experiences support people's abilities to learn more effectively, and this requires "preparation for future learning" assessments that are interactive and illuminate the conditions under which people change.

Brigid Barron, Stanford University
Technological Fluency Development across Contexts

This presentation examined the question, "How are out-of-school interests and learning activities a fertile context for developing adaptive expertise?" Barron presented a study on the Learning Ecology for Technology Fluency. This qualitative study documented several case studies from after-school settings as a context of fluency development. These cases examined issues of knowledge sharing, *meta-learning* (learning about learning resources), *resiliency* in the face

of interpersonal challenge or initial failure, and *collaborative competences* (e.g., willingness to support another's productive agency). The results of the case analyses indicated that studies of learning limited to examining school settings are likely to fail to understand the full extent of students' creative endeavors and thinking. Often, teachers are unaware that their students have acquired and applied remarkable skills and knowledge in informal contents.

Sean Brophy, Purdue University
(Conceded presentation time to allow additional discussion time.)

Valerie Crawford, SRI International
Adaptive Expertise in Science Teachers' Reasoning

Crawford and her colleagues are conducting a theory elaboration study to investigate adaptive expertise in science teaching. For a study using an authentic instructional problem-solving task, the researchers selected teacher participants identified as likely to be adaptive experts or routine experts, given their background characteristics, results of a questionnaire, and/or the researchers' knowledge of their professional practice. A group of novice teachers who had previously been involved in knowledge-oriented forms of work before entering teaching were also invited to participate. Participants were given an authentic student-work analysis task to perform, with a think-aloud protocol. For one analysis, researchers coded the transcribed protocols for utterances oriented to knowledge building and utterances oriented to efficiency (e.g., heuristics for completing the task, managing time). They found that although adaptive and routine veterans exhibited approximately equal amounts of efficiency, the adaptive veterans showed markedly more knowledge building in the course of performing the task. Novice teachers, in contrast, showed little mastery of the problem-solving heuristics that make problem solving efficient; at the same time, they showed levels of knowledge building approximately equal to that of the adaptive veterans, and markedly higher than that of the routine veteran teachers.

Susan Mosborg, University of Washington & Robin Adams, Purdue University and CELT
Investigating Adaptive Expertise

This research addressed the questions: "What characterizes adaptive expertise in engineering design?" and "How might it be developed?" To investigate these questions, an ill-structured task was used in which research participants were asked to design a playground. Participants were 19 expert landscape architects with broad experience. The task was self-timed, had no wrong answers, and included access to additional information. The researchers examined "expert framing" vs. "innovation" framing in experts' spontaneous comments about the design process. A contrasting-cases approach was used in the analysis. Participants were asked to explain aspects of their designs (e.g., why they might just add swing, slides). Adaptive expertise was operationalized in the following way:

- Innovation → pattern breaking.
- Efficiency → pattern following.

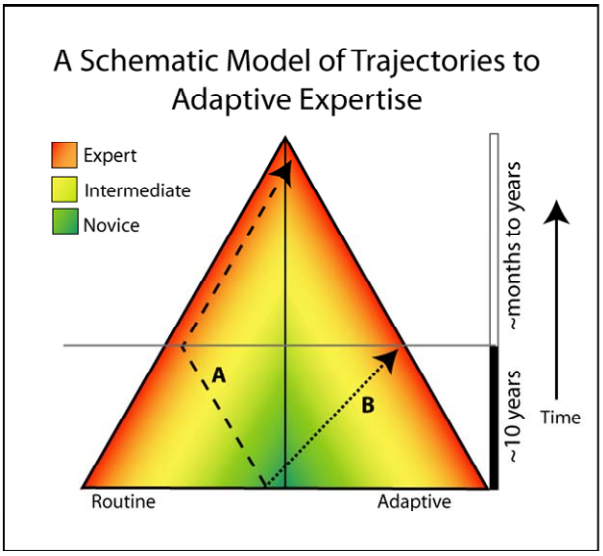
The analysis raised the following important questions for the researchers: “What counts as a *novel* problem?” and “What is the relationship between *innovative framing of the problem* and *novelty of the problem*?”

Lawrence Neely, Stanford University
Adaptive Design

This presentation examined the questions, “How to should we understand adaptiveness design?” “How do we foster adaptive behavior in design?” and “How do we recognize it that behavior and characterize it?” Neely presented a framework for conceptualizing and characterizing “adaptive design” as “a dynamic process by which designers manipulate the design process itself,” which is distinguished from “design” and “natural design.”

Vanessa Sivhla & Tony Petrosino, University of Texas, Austin
Conceptualization of Adaptive Expertise

This “on-demand” presentation discussed a graphical representation produced by the UT-Austin group of a developmental conceptualization of adaptive expertise: Notes about interpreting/Using Representation.



This diagram shows the trajectory, not just the end state, of adaptive expertise. A routine expert might not take the same path or trajectory that an adaptive expert does. It takes 10 years to develop adaptive expertise, and there are different routes to that expertise. An adaptive person can strive for expertise and achieve it in a shorter time than a routine expert can become adaptive. For the routine expert, more time would be required and the same path would be different.

David Sears, Stanford University
Testing a Framework for Promoting Adaptive Expertise: The Effects of Innovation and Efficiency Tasks on Collaborative Interaction and Learning

The study presented compared process and results related to two experimental conditions—one designed to promote efficiency and one designed to promote innovation. The experimental task involved creating concept maps in the Betty's Brain software environment. The two study types were dyad and individuals. In the dyad study, the efficiency group showed more partitioning and little difference from the innovation group in achievement. The innovation group started off with many errors. In the dyad study, the innovation group devoted more time to discussing each link in the map. More partitioning of tasks and handing off responsibilities, took place in the efficiency group. Few differences in learning emerged in the dyad study; however, significant differences were observed in the individual study. Sears concluded that innovation may be beneficial for individuals, but not for collaborators. The innovation problem in the dyad study may have been too simple; instead, innovation tasks may require a more complex problem. Moreover, the dyad study used recall measures, which may not have revealed the benefits of innovative instruction.

Joan Walker and Sean Brophy, VaNTH/Vanderbilt
Developing Assessments of Adaptive Expertise in Biodesign

In the context of a biomedical engineering design course (a yearlong capstone course), Drs. Walker and Brophy examined the following working definition of adaptiveness: "Competence coupled with the confidence to wing it." They examined the question, "Can we discriminate among people in terms of their developmental level of balancing innovation with efficiency?"

The study used design scenarios as a tool for measuring adaptiveness. Efficiency and innovativeness were operationalized in the task in the following way: Efficiency was evident in addressing the task question, "What do you need to do to test the doctor's hypothesis?" Innovation was evident in addressing the task question, "What questions do you have for the doctor?"

Using a cross-sectional, contrasting-cases study design, they examined whether students become more innovative and efficient over time. Participants' innovativeness was measured in terms of the questions they asked a doctor in order to produce a design. Participants' efficiency was examined in terms of a rating of the quality of strategy. Findings indicated that efficiency and innovation are separable but related dimensions of adaptive expertise.

Small-Group and Whole-Group Discussions

After the presentations, participants broke into small groups to construct a representation (on chart paper) that illustrated the major *phenomena* of adaptive expertise and the various uses of the *construct* of adaptive expertise employed to describe and study those phenomena, and to explore how they related to each

other. The results of each group's work were presented in a concluding, whole-group discussion.

The second day focused on deeper examination of core constructs and comments by consulting experts in expertise research, supplemented with discussions with the experts. The day began with an informal panel discussion by the consulting experts, Drs. Chi, Patel, and Nelson. Dr. Branford was then asked to comment on aspects of the discussion and share his emerging thoughts on adaptive expertise. Next, participants again broke into small groups; one group formulated important research questions in the domain of adaptive expertise, a second group constructed a representation of the conceptual domain, and a third group discussed methodologies in the study of adaptive expertise. The entire group then discussed key points from the panelists' comments and from the small group discussions. Finally, participants discussed formats and forums for exchanging ideas and research products to sustain the discussions that had occurred over the 2 days.

Symposium Discussion Themes, Topics, and Issues

In this section, we present a summary of key themes that cut across symposium discussions. This summary is informed by our own theoretical perspectives and does not represent the proportionality of comments on various topics and themes.

The major themes that cut across discussions and presentations at the symposium were: conceptualizing adaptive expertise; defining the relationship of adaptive expertise with personal characteristics, including affect and motivation; understanding and distinguishing between adaptive expertise and expertise *per se*; and exploring implications of adaptive expertise for instruction, assessment, and other areas of interest to the participants. Participants also discussed professional judgment and its relationship to adaptive expertise, as well as the acquisition of judgment through practice.

Conceptualizing Adaptive Expertise

Much of the discussion was concerned with conceptualizations of adaptive expertise. The key issues related to this topic were: the view of adaptive expertise as a balance of mastered skills, knowledge, and abilities, and the ability to let go of or to work outside routines in applying knowledge to new contexts, to approach familiar problems in new ways, to build knowledge through problem solving, and to innovate processes and solutions.

Adaptiveness: A Balance of Innovation and Efficiency

In his initial remarks, Dr. Bransford noted that the concept of adaptive expertise derives from the work of Hatano and his colleagues, who studied farmers, abacus experts, sushi chefs, and other types of experts. Dr. Bransford shared some quotations that communicated the importance of routines and the difficulty of breaking out of them: “Habit is the fly wheel of society”; and “Genius is 90 % unhabituated perception” (William James). In the conceptualization of adaptive expertise set forth in Schwartz et al. (2005), adaptive expertise is described in terms of a balance between efficiency and innovation. Without efficient heuristics and routines, one is rudderless and overwhelmed (like a novice). Without some innovation, one cannot work in the “whitewater” of frequent change, characteristic of today’s world. The “corridor of optimal adaptivity” described in Schwartz et al. (2005) is the corridor of “working smart.” This is similar to “new mind” (Buddhism’s “beginner’s mind”): one has to be able to adjust one’s mindset because the world changes so rapidly.

Rather than canceling each other out, innovation and efficiency form an important combination related to the display of adaptive expertise. An example of this is seen in studies conducted at Harvard University of people learning to operate telegraphs. Operators must be able to automatically convert verbal language to code without delay so that they can interpret and comprehend the message. Without efficiency, attention is overwhelmed with details.

An important “meta” component to being adaptive involves judging when to be efficient and when to be innovative. Sometimes efficiency is the appropriate course of action. Sometimes innovation is required by changes in the environment; not innovating would result in an incomplete or inappropriate solution to a problem. Often, one has a choice: “I can make this into an efficiency problem, or I can make this into an innovative problem.” Whether a person chooses innovation or efficiency in a given problem is shaped by the problem solver’s situation definition (the functional task space).

The potential task space can yield differing functional task spaces for different problem solvers. Task framing is the first step in problem solving. Problems that are considered “wicked” are those the problem solver does not know how to represent (frame). Similarly, the novelty of a problem or situation is relative to the problem solver. The routineness or novelty of a problem is relative to the problem solver. Therefore investigation of adaptive expertise needs to take into account the context on the one hand and the individual’s judgment and developmental trajectory on the other hand.

Gaining efficiency involves a trajectory of mastering skills and building schemas (Rumelhart & Norman, 1978). Schemas help us interpret new situations relative to old experiences and act efficiently on the basis of known, successful experiences. For example, in medicine it is often necessary to act quickly, without time for reflection or experimentation. Another example is seen in standardized test coaching: coaches help test-takers turn novel problems into routine problems by teaching the basic patterns of question types. The test-takers’ *schemes* for the “hard” problems help them approach the problems *efficiently*. In many domains, good schema-based routines are necessary for completing activities. For example, chess experts recognize patterns in the pieces that allow them to quickly identify the state of a game and potential next moves. Heuristics for solving problems is important to efficiently framing and solving a problem.

Adaptiveness is important because it is sometimes better to invent a new strategy when the old strategy no longer works in a new or changed situation. Although old routines may continue to be successful, these routines can impede our abilities to get better, and the change sometimes requires getting worse before getting better (Patel & Groen, 1991b). For example, a certain tennis swing may be adequate, but ultimately limits a player’s flexibility. As the player learns to rework her swing, her performance may worsen during the transition to the new swing. Relearning often involves a time of reduced performance as the learner continually tests and refines her application of the skill.

Describing Adaptive Expertise

Much of the symposium discussion focused on describing adaptive expertise. Two main topics were elaborated in this vein: cognitive flexibility and the role of judgment.

Cognitive flexibility. The themes of flexibility in building and applying knowledge and of flexibility in applying or altering routines were prominent in discussions. Another example of the occurrence of adaptiveness was provided. The problem involved getting a bird out of a classroom. In the course of attempting this, the problem solver reframed the problem from, "How do I get the bird out of my class?" to "How do I get the bird to *want to leave*?" Participants also described cognitive flexibility as involving *holding one's theories lightly*. One participant characterized cognitive flexibility as "nimbleness." Both adaptive experts and routine experts use routines, but only adaptive experts "unpack" the routines.

Judgment. The relationship of adaptiveness to professional *judgment* was discussed. One example of the importance of judgment in emergency medical care was noted: each case is different and doctors need to *act, fast*. Thinking quickly, recognizing incomplete information, managing uncertainty, and acting quickly based on information are critical factors in making effective and efficient decisions in emergency situations. Doctors have to be good not only at creating knowledge just in time, but also at developing good heuristics based on this knowledge. Similarly, in crisis management, judgment is critical. Judgment is knowledge that is inseparable from the knower. Judgment entails skill development and tool use as part of routines, but provides vital information to help with the application of knowledge and skills to specific contexts, situations, and problems. In this way, judgment is important in innovation processes.

Basis of Adaptiveness

Participants also discussed the underlying basis of adaptive expertise. Although adaptiveness was commonly viewed as an optimal balance of efficiency and innovation—both over time and in the context of specific tasks—participants also discussed the characteristics that contributed to an individual's ability or decision to innovate or learn something new rather than doing something familiar. Two themes in this connection were *willingness to change* (e.g., to try something new, to use others as resources for learning and development) and *comfort with taking managed risks*.

Willingness to change. Participants discussed the social, emotional, and motivational dimensions of adaptiveness. These dimensions were both implicit and explicit in comments about the importance of willingness to change. Adaptive expertise has strong connections to the conceptual change literature. However, preconceptions or misconceptions do not necessarily affect our lives unless we are scientists. But in social situations, changing one's conceptions can be important to effective action, interaction, and collaboration.

Social interaction can play a role helping individuals recognize the need to change. We often resist or fail to recognize this need to change. We need people who will argue with us, with grace, and who can cede the point when appropriate. In the working world, learning from others is often the key to changing. Industry research has found that those who do well in school but not in companies are

frequently not good at learning from others. As a mindset or disposition, adaptiveness entails actively seeking feedback from those who are *not* likeminded. Ego and motivation have roles in the extent to which we are able to learn from social others and from social interaction: we like to surround ourselves with likeminded people. But greater flexibility and adaptiveness result from being surrounded by diverse ideas.

Comfort with risking mistakes and saying "I don't know". Adaptiveness involves the willingness to take risks and to make mistakes in attempting innovation. It entails feeling comfortable with departing from familiar ways (and possibly failing in the process). Adaptiveness can be fostered in organizations by building into the culture/structure opportunities for people to make mistakes and cultivating the view that experimentation and innovation are valued practices, but ones that do not always lead to success. An example mentioned was the case of a software firm that viewed software developers as requiring the chance to innovate in their work on occasion, rather than carrying it out; allowing the developers opportunity to innovate contributes to the firm's competitiveness.

Distinguishing Adaptive Expertise from Expertise

An important question raised in the symposium was whether adaptive experts are simply more advanced experts. Research on medical reasoning provides a basis for distinguishing between an adaptive expert and an expert. Adaptive experts can override the routine and often highly automatic diagnostic heuristics and schemata when it is appropriate and engage in a deeper, more constructive reasoning process. Adaptiveness in this sense includes not dismissing the novel and recognizing anomalous problems as novel, rather than misrecognizing them as routine. One study of medical diagnosis, for example, involved giving experts a hard-to-diagnose case (Feltovich et al., 1997). Most of the experts came up with a diagnosis that was incorrect but that accounted for most, but not all, symptoms. These experts decided the unexplained symptom was unrelated, not important, or an error in the data. However, the flexible expert did not dismiss the hard-to-account-for symptom. He continued to think through the problem to attempt to account for the final symptom and produced the correct diagnosis. This expert can be described as adaptive because he thought through the problem space more thoroughly, deliberatively, and metacognitively. He mentally constructed a model that accounted for the final symptom with a different diagnosis. That expert achieved superior performance (correct diagnosis) and used a process that differed from those of the other experts.

Medical research on diagnosis shows that not all experts are adaptive and that degree of adaptiveness can vary. Experts are *usually* adaptive persons, but are also those who have many routines—the routines, in fact, make them experts. In the practice of medicine, it is important to be quick and efficient. It is also important to follow heuristics associated with common diagnoses. The critical question is: How adaptive is or can this expert be, when adaptiveness is called for? Whether a departure from routine is called for is a key issue. Sometimes, as

in medicine, experts have to act quickly. Carefully identifying and thinking through alternatives are not always possible. Doctors have to *treat*, often very quickly, and be competent in that routine. Thus, efficiency plays an important role in problem solving. Moreover, efficiency—usually in terms of mastery of procedures—enables one to cease conscious monitoring of one's application of procedures to determine whether or not they require change.

Another example of a research study that aimed to distinguish adaptive expertise from expertise is Wineburg's study of historians working in a novel domain (1998). Among the characteristics of adaptiveness identified in this study is building new knowledge through problem-solving, as opposed to merely applying knowledge. One expert showed a greater ability or willingness to transfer his knowledge to a new domain. Thus, willingness to think things through, when the occasion calls for it, is an important characteristic of adaptive expertise.

Participants discussed adaptive expertise in terms of schema theory. It is possible that adaptive expertise can be cast in terms of schema theory. Adaptive experts would be described as those who *modify* their schemes rather than just applying them. However, as was further noted, it is sometimes necessary to "totally toss the scheme." Participants noted, too, that it is also possible that schemata are too rigid to be considered a basis for adaptive functioning.

Discussions characterizing the difference between research on expertise and research on adaptive expertise also noted that a key concern for adaptive-expertise researchers is understanding the *dispositions* that should be fostered to prepare students for the 21st century. That is, we need to enable people to build knowledge and be innovative throughout their lives, in step with rapidly changing circumstances, technologies, and problems. Learning is a critical focus for most studies of adaptive expertise research and is a key way that adaptive expertise research differs from research on expertise *per se*. Participants noted that knowing how experts do something does not translate into a recommendation for instruction to promote the development of expertise. To understand how expertise develops, it is necessary to examine learning. In adaptive-expertise research, learning episodes are examined to determine, for example, the role that learning conditions play in the propensity to innovate. Similarly, it was noted that two approaches are taken to the study of expertise: (1) to understand how novices become experts, (Patel & Groen,1991a, 1991b) and (2) to understand expertise to understand its trajectory (cf. Chi, 2006a, 2006b).

Implications of Adaptive Expertise for Instruction, Assessment, and Other Areas

The discussion of adaptive expertise highlighted critical assumptions about our goals for learning, how we teach to these goals, and how we assess the achievement of these goals. Much school instruction focuses on developing efficient skills, and assessments are designed to measure that efficient application of skills. These assessments also measure learners' ability to apply prior knowledge without access additional resources. That is, the problem-solving

context is sequestered. What we do not test is learners' recognition of the need for additional knowledge, or their ability and willingness to change in new situations or to access resources, including tools and social others, to learn skills or knowledge needed for the new context or problem.

The model of adaptiveness as an optimal balance of efficiency with innovation (represented in the diagram in Figure 1, from Schwartz et al., 2005) provides a theory of *change*. The diagram helps us analyze the following kinds of questions: Who is going to change? Who is going to seek feedback? What are they learning now, and what are the indicators of where they will be next? Are learners pursuing information to help confirm predefined routines, or are they gathering information for more effective problem framing? How do learners use current information or knowledge to inform where they will go next?

These questions highlight the need to look beyond instruction and assessment that approach the transfer of knowledge only in sequestered problem-solving contexts. Given the increasing need for continuous learning, more emphasis needs to be placed on instructional methods to prepare students for future learning. Teaching for adaptiveness cannot be done through instruction in basic skills or through application of heuristics. The conjecture is that to foster adaptiveness, opportunities for learners to adapt their developing skills, knowledge, and abilities need to be embedded throughout their learning experiences.

Much learning in the professions occurs by tacit acquisition. It is important to consider how to engineer learning experiences in the context of practice to encourage people to become adaptive through their learning.

An important question for symposium participants concerned measuring adaptive expertise. It is likely that people who perform well in sequestered problem-solving activities will be unable to perform as well or adequately in "real world" or authentic problem-solving situations.

Participants also discussed whether we measure efficiency separately from innovation. Another challenge for the measurement of adaptive expertise involves the relative nature of novelty to the individual and the need to determine what is novel for given individuals in order to evaluate their responses to novelty. To evaluate adaptiveness for an individual, it is necessary to know that the problem is truly novel for the learner. It is also important to be able to distinguish novel problems from novel problem *framing*. The latter may be an example of innovation. Measurement of innovation or adaptiveness raises the issue of the relative nature of adaptiveness, from the perspective of learning and development. A novel problem for an individual may not be a novel problem in *that individual's field*.

Instruction and Fostering Adaptive Expertise

New ideas for instruction emerge from a focus on adaptive expertise. Instruction should foster in students a mindset of innovation from early on. Instruction should include the cultivation of innovativeness and the ability to apply knowledge to novel or real world problems, rather than assuming individuals will be able to do this after schooling. An approach to achieving this goal is the use of a cyclical problem solving, in which learners have an opportunity to try something out, obtain feedback, and try again. As part of this approach, learners need to be taught to obtain and to use feedback effectively to adjust their learning and problem-solving process. Some learners cannot use feedback effectively or cannot respond to it effectively.

Efficiency, schemas, and routines can lead to functional fixedness (the "tyranny of success"—"This has worked 100 times before, so we'll do it again!"), making it difficult to have a mindset attuned to change. When situations change, old routines no longer work. Therefore, for innovation to occur, efficiency must be deemphasized and something new attempted. Doing so may require a reduction in performance for a time as the learner develops new understanding.

This idea of learning with understanding versus learning routines illustrates that embedding innovation in instruction can develop learners' ability to let go of old ideas that do not work by pursuing new ideas that may yield better outcomes. Many of the presentations on engineering and design demonstrated these ideas.

Innovation and Adaptive Expertise: Criteria for Innovation and the Occurrence of Innovation

As they sought to interpret the interaction of efficiency and innovation, symposium participants raised other important questions, such as, "Can we have an innovator who is not an expert (e.g., the so-called "hidden artists" who do not work in a discipline or a community)?"

The adage, "discovery favors the prepared mind," implies that a person who has deep familiarity with the important ideas in a domain is going to notice something that is recognized as novel by the community, not just the individual discoverer. In this connection, opportunities for change require knowing what the current state is and being able to critically evaluate its shortcomings. Without such preparedness, adaptation cannot occur spontaneously for an individual, and a person outside the domain will be required to pose the question.

Many things are so tacit that we fail to realize that they are part of us (e.g., Garfinkel's breaching experiments in the 1970s, which revealed that tacit everyday knowledge by having some violate the norms of everyday behavior). These habits of mind can constrain innovation.

Interactions with other can provide a catalyst for innovation. Service to a community (e.g., scientists, engineers, clients, collaborators) requires understanding and supporting the needs of others. Innovation occurs when

creative ideas become part of people's lives and they transfer those ideas to activities that help others.

Is innovation the same as being generative? Literature on learning talks about constructing generative learning environments as a necessary part of learning with understanding. We can all probably identify situations in which people can generate something novel, but the innovation is not deemed appropriate by the community. Being generative is part of being innovative, but an innovation is something that is recognized by a community of people as representing something new and valuable in some way.

These discussions of innovation highlight that innovation is not just novelty, but novelty that also is closer to an ideal state. We can identify "wicked" problems to be solved and redefine them into tame problems. However, if the tame solution does not change the current state to a more ideal state, it is not innovative. Knowing and defining the ideal solution are big parts of problem framing discussed earlier.

Distributed Adaptiveness and Adaptive Organizations

Adaptiveness in not limited to individuals; organizations can also be adaptive. For distributed adaptiveness to be achieved, having the right kind of communication and developing a common framework are essential. A distributed social system has to have a diversity of people in different roles. It is important to distinguish between *driving* innovation and *enabling* it to emerge.

Groups of individuals can form a highly innovative team that surpasses the abilities of individual team members. Symposium participants noted the importance of exploring how successful teams make judgments and decisions to identify new opportunities they had not recognized before. Doing so requires the right kind of communication among team members. Part of this communication could involve taking steps to develop a common framework shared by all the participants.

Many organizations stifle adaptiveness because employees are worried about doing something wrong. An organization needs to promote risk taking by allowing people to feel safe to innovate and to make mistakes. In adaptive organizations, people feel safe to innovate and take the risk of making mistakes. Adaptive organizations have built in opportunities for people to make mistakes. These are organizations that are willing to refine their mode of operation to accommodate rapid change of technologies and markets. To maintain efficiency, innovation needs to be managed so that results can be achieved with acceptable parameters.

Adaptive Expertise and Design

Design and adaptive expertise were linked in many of the symposium presentations, as well as in the discussions. Two main themes emerged in this linkage: the importance of innovation in solving engineering and design problems, and the need among scientists, clinicians, technicians, engineers, and designers for continuous, career-long learning through practice. Researchers investigating education in engineering, science, and medicine are concerned with understanding how to foster students' ability to be innovative. Fostering students' disposition toward continuous learning is also important, because students will work in a world in which conditions, contexts, tools, and problems change rapidly.

The importance of informal learning and learning through practice was addressed in several of the presentations on research on adaptive expertise, as well as in comments made by the discussants. Dr. Nelson described the acquisition of judgment (wisdom in decision making) over time through professional practice, where wisdom entails an orientation toward the ideal rather than the practicable or the actual, as well as empathy with those for whom one designs solutions, whether for social systems or specific technologies. Dr. Chi described the acquisition of second-order knowledge and orientation in problem solving to second-order features through learning in the course of practice. Second-order knowledge is learned through doing and cannot be taught explicitly. Similarly, Dr. Patel discussed the importance of medical practitioners learning through practice to enhance their formal knowledge so that they can be effective, accurate problem solvers in fast-paced clinical settings. The importance of learning through practice and the nature of tacit learning have important implications for the design of learning environments.

Consulting Experts' Reflections

In this section, we present summaries of the invited comments by the consulting experts and offer critical reflections on cornerstone issues.

Drs. Micki Chi, Vimla Patel, and Harold Nelson were invited to the symposium to serve as expert consultants. The consultants presented a panel discussion and participated actively in other aspects of the symposium.

Drs. Chi and Patel are experts in expertise. Because many of the symposium participants are studying adaptive expertise in terms of innovation in design of technologies and in engineering, Dr. Nelson was invited to comment and consult on the notion of adaptive expertise, particularly with reference to the topic of design.

Dr. Chi's discussion focused on whether or not adaptive expertise constitutes more advanced expertise. She presented two main perspectives from within expertise research that support that view. Dr. Nelson discussed design as a third way of knowing and doing, along with science and art. He also discussed the notion of judgment and its importance in the design of social systems. Dr. Patel's comments focused on the nature of expertise as involving both efficiency and adaptiveness and the importance of considering human problem-solving processes in the design of technologies to support human performance. (For a general review, see Patel, Arocha, & Zhang, 2005.)

Micki Chi's Comments

Dr. Chi's primary comments pertained to the issue of identifying a systematic distinction between adaptive expertise and expertise *per se*. Dr. Chi made the following two main points: (1) It is not clear that there is evidence that an adaptive expert is not a more advanced expert. Adaptiveness could be on the same trajectory as expertise—and thus a more advanced form of expertise. (2) Adaptiveness may be essentially the same thing as transfer. If so, that would imply that routine experts (in contrast to adaptive experts) are those who cannot "transfer in" their knowledge for some reason (e.g., because that knowledge is context-bound, inert, inaccessible, or incomplete). Dr. Chi presented several lines of research on expertise to clarify and elaborate on these points.

She commented that perhaps "adaptive experts" are those who operate with rules that are *less bound to specific conditions or contexts*. This implies that the answer to point (1) above is that the routine expert has not generalized the conditions of her rules. An example of that provides insight into what might be involved in prompting adaptiveness: In a study conducted by a post-doctoral student of Lauren Resnick, students were given a parallelogram and scissors. They were asked, "What do you think I'm going to ask you to do?" That question created an opportunity for them to reflect, which might also be an opportunity to become adaptive in a problem setting. Reflection may be a key to prompting

adaptiveness. If so, this assumption supports the view that routine experts are experts who do not, for whatever reason, transfer their knowledge to novel or nonroutine problems.

Another approach Dr. Chi offered for conceptualizing adaptiveness as greater expertise was the following: cognitive psychology incorporates the notion of first-order rules, which are surface oriented, and second-order rules that are deeper. A routine expert might have a greater tendency to operate with first-order or direct rules or might have formulated fewer second-order rules. An adaptive expert would operate with deeper, second-order rules, which are more broadly applicable. Adaptive experts then, operate with greater knowledge of, or greater orientation to, second-order features than first-order features. Experts who operate in terms of second-order features or with orientation to more system-wide features are more adaptive because they can apply their knowledge to a wider range of situations.

Dr. Chi noted that many differences in children's abilities to transfer knowledge in solving mathematics and physics problems can be explained in terms of their use of first-order or second-order rules. She also provided the following example of application of first-order vs. second-order rules: A researcher interviewed an expert swimming coach and another, less expert coach and asked both to diagnose what was wrong with a swimmer. The not-so-expert coach picked out discrete features (e.g., the right stroke is not over the head). The superior expert addressed the diagnosis in a holistic analysis of the swimmer's whole body, as opposed to discussing discrete individual features.

This formulation, in Dr. Chi's discussion, led her to the following question: "Are experts who use more second-order features more *adaptive* because they are more expert?" A related question is, "How did they derive the second-order features, which are not taught?" Those features are learned from practice, through implicit learning.

Dr. Chi briefly discussed the acquisition of second-order rules. Typically, second-order features cannot be taught; instead, they belong to a category of knowledge that John Brown has called "stolen knowledge" (Brown & Duguid, 1996). For example, second-order rules are important in domains with phenomena for which there is no direct causal agency (as in natural selection). Diffuse knowledge, such as knowledge of phenomena with no direct causal agent, embeds second-order features.

In the realm of practice, many second-order rules are learned *through practice* rather than through formal instruction. Cues that may be important in problem solving in a domain are not explicitly taught, and experts may not know them. One example of learning second-order rules by extracting them from practice, not explicit instruction, is seen in medical residents learning through accompanying the attending physician on rounds each day. The attending physician rattles off cues by asking questions or obtaining information—body temperature, blood pressure, etc. Residents learn in accompanying the attending physician by

paying attention to the conversation and communication. What is said points out what is being considered and what is important to attend to.

Dr. Chi also addressed the idea of whether or not adaptiveness entails a greater level of expertise: an expert given a nonroutine problem to solve will either look like a novice or an adaptive expert in doing so. Is a routine expert therefore just more novice-like (less expert)? If so, this would imply that adaptive expertise is an indication of a greater level of expertise.

If adaptiveness is essentially the same thing as transfer, this would imply that routine experts are those who cannot "transfer in" their knowledge, because it is context-bound, inert, inaccessible, or incomplete. Dr. Chi asked, "What can be done to make a routine expert more adaptive?" She also pointed out the concept of an adaptive expert requires the corollary concept of an adaptive novice. Therefore, the characteristics of an adaptive novice need to be specified.

Finally, Dr. Chi remarked that experts are both adaptive and routine. Routineness and adaptiveness both offer benefits and strengths, and both have shortcomings. Drawing from her chapter, "Two Approaches to the Study of Experts' Characteristics" in the *Cambridge Handbook of Expertise and Expert Performance* (Chi, 2006a), she presented a list of key strengths and weaknesses of each type of expertise and asked participants to consider the list's adequacy and whether the set would also apply to a novice (see Table 1).

Table 1. Comparison of Adaptive and Routine expertise

Type of Expertise	Skills/ Excel in …	Shortcomings/ Fail in …
Adaptive	• Generating the best solutions • Scoping out problems • Monitoring comprehension • Employing strategic thinking • Being opportunistic	• Details glossed over
Routine	• Detecting and recognizing patterns and key information • Exerting minimum cognitive effort	• Domain-limited • Overly confident • Context-dependent • Inflexible • Inaccurate judgment • Bias and functional fixedness

Harold Nelson's Comments

Dr. Nelson's comments focused on *design* as *tertium quid*, a third way of knowing and doing, different from science and art, but fundamental to the nature of humans and humanity's way of being in the world. He also commented on the importance of *judgment* as a means of knowledge creation in a form that is inseparable from the knower in the application of knowledge to problems.

The ability to design is the first capacity for meaning making that humans exhibited historically, Dr. Nelson pointed out. We typically say humans *discovered* fire or invented the wheel, but they didn't; they *designed* them. These technologies were not something merely stumbled across by accident or good fortune.

Dr. Nelson argued that we should consider design as a third form of a culture of inquiry, not an applied science or art, but its own tradition. Design is inclusive of science and art because it is both rational and esthetic. It combines qualities of what is true, real, and ideal. In systems design, we compose, pull together, build, and create, rather than displace truth. It's a form of disciplined inquiry into what's true, and what should become real, based on what is considered to be ideal. People are looking for ways to make sense of the daunting challenges they face in their lives and to intervene in the complex, dynamic world confronting them. There is an immense, challenging frontier in this area of professional and scholarly development.

Intrinsic to his conception of design are the ideas of *intention* and *service*, which are made explicit through judgments. Empathy—an essential quality of service—is critical, he argued, because in designing; the designer makes judgments on an others' behalf. Dr. Nelson pointed out that what is traditionally considered to be a characteristic of good, strong leadership can map onto an attribute shared by sociopaths in that they are not expected to show empathy. He pointed out that some organizations now are attempting to redefine leadership in a way that gives a higher priority to the notion of judgment and the important role of empathy in design.

Dr. Nelson drew a connection between judgment and adaptive expertise. He described how, in philosophic traditions of the past, *sophia* (wisdom) was knowledge that was an integration of reflection, and action The Socratics, however, divided *sophia* into two distinct forms of knowledge—knowledge of first principles (reflection) and knowledge for action, with reflection moved to the top of the hierarchy of types of knowledge and action-focused knowledge moved to the bottom. Most universities, for example, deal with knowledge created for the top of this hierarchy and relegate action related knowledge to the bottom of their research interests. He said that today, students in design-related fields are trying to find ways to reconstitute *sophia*. He argued that we need to do that now from an explicit design perspective. Otherwise we pay too high of a cost if we continue to separate thinking and acting in the world. Adaptive expertise researchers

should think about their work in a broader and deeper way for example, in terms of systems and design.

Dr. Nelson described the need to bring judgment and decision making into some kind of balance. For example in most grant proposals, he stated, outcomes are required to be measurable up front, but outcomes based on judgment are susceptible to measurement and evaluation only after the fact. Judgment is a *full knowing*, only revealed through actions. As a designer, he stated, one is expected to discover what "it" should look like. The designer is held accountable for that. The challenge is what do designers have to know in order to trigger and facilitate desirable changes in social systems? The advancement of systems science, the logic of design, allows us to take design more seriously and to see designing as a valuable form of expertise.

Vimla Patel's Comments

Dr. Patel has extensively explored adaptive expertise in medical reasoning. She focused on the importance of adaptive expertise in the practice of medicine; on the need for strong design principles in the design of medical technologies, so that technology supports human performance and the way that humans work, rather than requiring humans to adapt to technology; and on the linking of adaptive expertise with reflection.

Dr. Patel noted that there are many conceptions of adaptive expertise. The task of advancing knowledge in this area requires formulating a conception of it, describing it, and testing it. She argued, that to move forward in a productive way, it is important to make explicit the assumptions and underpinnings of one's conceptualization of adaptive expertise. What constitutes adaptive expertise and under what conditions? She said that the theoretical framework should be elaborated, the working hypotheses stated, and a good empirical test performed. There are too many assumptions, but they are not enough empirical work to support them

Dr. Patel also pointed out that a notion of adaptive expertise requires a corresponding assessment of it. Designing good assessment tools is important to the study of adaptive expertise for two reasons: (1) assessments are needed to relate theoretical aspects of adaptive expertise to performance; and (2) good data are needed to be able to convince people to change, if necessary. In medical education and elsewhere, deans of schools want to know precisely what to change and how much it will cost. Given that they have a short attention span as far as making changes based on research data, the data and the argument have to be very persuasive.

Dr. Patel outlined key ways that adaptive expertise is important in medicine. One key role is in continuous learning through practice, and the other is cognitive flexibility in the application of knowledge learned in a formal instructional context to a clinical context involving patients. Few medical schools admit students with broader education involving the arts or philosophy. Instead, they usually admit

only those who excel in natural and biological sciences, given that these are strong predictors of success in medical school. Young science students are able to *recall* massive amounts of information in the medical school curriculum better than mature, philosophically oriented students. In practice, however, students with biological/natural scientific backgrounds have a difficult time with patients later in their professional trajectory than those with the broader backgrounds. Many transformations of knowledge must occur from biological sciences, to pathophysiology, to clinical medicine, to working with patients. Therefore, considerable learning continues over each stage of medical professional development. For example, in practice (versus during formal education) doctors have to shift from "cause-to-effect" reasoning to "effect-to-cause" reasoning. Medical students learn that "infection causes fever" as a causal phenomenon, but in practice, they must reason backwards. For a patient who presents with fever, doctors must infer that if fever exists, then infection must also exit.

Researchers seek to understand in what circumstances and why people *shift* their thinking so that they can apply formal knowledge flexibly in contexts quite different from those in which they learned that knowledge. What facilitates such shifts, and how can they be supported to make transition easier? Dr. Patel asked, "How do we foster adaptiveness through the nature of the environment?" The question, she pointed out, should start with the nature of the environment in which people will *apply* the knowledge that we teach them formally. What do we need people to learn, to know, and to be able to do? What do we need to foster that learning?

Dr. Patel noted the frequent mention in symposium discussions about *reflection*. In medicine, because working in the field provides no time to reflect, how do doctors learn? She offered the following description: They have to act quickly under time constraints (reflexively), when they have no time to think but only to do, based on the available information "in time." However, when something goes wrong, they have to reflect on what happened. In weekly meetings in critical care department, the critical events are discussed with colleagues. The event is analyzed and reflected on by a group. Different perspectives are accessed to come up with solution so that the next time the problem arises it is handled differently. The outcomes of these discussions are formulated into new routines (Patel, Kaufman, & Magder, 1996)

In learning through practice, doctors are constantly changing as they encounter obstacles. A big concern in medicine is medical errors. They will never be eradicated, so they must be *understood* instead, so that we can design systems that are *adaptive for us* as human beings to use. We are certain to make errors, but we want to support human performance (via information systems), which will help us reduce serious errors. Experts in critical care make as many errors as do intermediate-level performers, *but they recover faster from these errors*. In fact, it is hard to even *see* their errors because they recover so quickly. In some sense, therefore, such mistakes are not really errors, but evidence of adaptability in trading off serious errors for lesser ones.

Dr. Patel noted that as health care changes, medicine's collaboration with technology is increasingly important and an area of significant concern. In the area of clinical collaboration, nurses collaborate with doctors and social workers, pharmacists, ethicists, and so forth, and the individual expertise and contribution of *each* person to the teamwork is critical. Individuals have to be able to appropriate new information and act autonomously. It is not enough to say, "We can all work together." To collaborate deeply, medical personnel need to *transfer* what they have learned to other situations. If they are tied to the context too tightly, then transfer of knowledge is difficult. Therefore, good technology design is important because that design influences behavior more than is generally realized (Patel et al., 2005).

Reasoning with technology is different from when technology is not used. Working with and without technology entails both pros and cons, and a compromise is needed. Many problems are related to the interface with technology in practice because technology generally has not been designed to be congenial to the way we think. This lack of complementarity is becoming a significant issue in medicine. Expertise now requires collaboratively drawing on both internal mental resources and external technological resources. The two types of resources can both complement resources and be distributed socially in completion of a task.

Critical Reflections on Adaptive Expertise

This section presents the authors' critical reflections on cross-cutting issues raised in symposium discussions that are important in advancing research on adaptive expertise and its development. The symposium was designed to encourage discussion of the definition of adaptive expertise and its implication for learning, instruction and assessment, with presentations to provide focused articulations of the strengths and limitations of specific frameworks and operationalizations of adaptive expertise. In these discussions five interlocking issues emerged that particularly merit further consideration: (1) distinguishing adaptive expertise from expertise per se; (2) elaborating the aspects of adaptiveness that are separable from the structure of knowledge and cognitive processes in its application; (3) the focus on learning and development in adaptive expertise research; (4) methodology in the study of adaptive expertise; and (5) the context-embedded nature of adaptive expertise. In what follows, we briefly discuss key issues in connection to each of these points, with a concern to highlight issues requiring further theoretical elaboration and empirical investigation.

Distinguishing Adaptive Expertise from Expertise

A key issue raised in the symposium is the need to formulate a clear and coherent distinction between expertise and adaptive expertise. During the symposium, the need for greater conceptual distinction was articulated in connection to the question posed by Micki Chi as to whether the performance and problem-solving characteristics that symposium participants described in terms of *adaptive expertise* could not be described as a more advanced form of expertise and accounted for in terms of constructs and findings related to expertise *simpliciter*. For example, adaptiveness may be described in terms of an expert's operating with more second-order rules and features (as opposed to first-order rules and features) such that she is able to apply knowledge more flexibly and creatively to novel problems.

Expertise rests in the amount and type of knowledge an individual has acquired as well as in the organization of this knowledge (Sternberg, 1997). Adaptive expertise researchers, on the whole, view adaptive expertise as involving not only knowledge and distinctive cognitive processes but also habits of mind, dispositions, and other personal characteristics that support successful problem-solving and performance. Moreover, the functioning and application of these characteristics is in some respects independent from the application of deep domain knowledge.

A well-known study of expertise in radiologists makes the distinction between adaptive expertise and expertise in the context of expert/expert research in radiology (Raufaste, Eyrolle, & Mariné, 1998). In our analysis the study demonstrated that some expert radiologists, because of the nature of their professional practice, developed a "habit of mind" of employing deliberate,

explicit reasoning during problem solving rather than the more automatic types of reasoning typical of routine expertise. This study of radiologists included both "basic experts" (experts who had practiced radiology for at least 13 years) and "super experts" (experts considered outstanding among top specialists). The study included novices (first- and second-year residents) and intermediates (third- and fourth-year residents) for comparison. These authors found very large differences in problem solving processes and performance between the basic experts and super experts. They found that both basic experts and super experts were accurate in diagnosing a disease with highly salient visual cues. However, for a disease with subtle visual cues, basic experts had very poor accuracy in diagnosis. When the cues were pointed out to them, the basic experts diagnosed accurately. Super experts, however, engaged in a deliberate problem solving process and were much more accurate than basic experts in diagnosing disease indicated by subtle cues.

The authors interpret the difference in performance as due not to differences in knowledge but to differences between the nature of professional practice for the two groups. For basic expert radiologists, professional practice primarily involves the clinical work of diagnosis with X-rays. They become highly efficient in this practice and therefore are highly efficient with routine forms of data and types of disease. This high level of efficiency means that for nonroutine cases, nuances and oddities in data are likely to be glossed over and that diagnosis accuracy will be low. The professional practice of super experts, in contrast, includes not just clinical work but also teaching and research, both of which entail the use of explicit and deliberate reasoning. Thus, the professional practice of these super experts involves a high degree of deliberate practice, close attention, and reflexivity—explicit reasoning and justification of conclusions to themselves and others. These habits of mind carried over to the interpretation of X-rays in the diagnosis of disease in the laboratory study. Super experts were not only more accurate with their diagnosis of nonroutine pathology, but they also demonstrated an elaborated and integrative cognitive reasoning process that was not seen in the other groups. In short, super experts engaged in a deliberate and elaborated reasoning process that was not curtailed by over-efficiency in the diagnostic process.

This findings from the expert/expert study of radiologists are similar to Wineburg's study of expert historians (1998). He found that an expert historian who was given novel content to interpret engaged in a deliberate, constructive, and metacognitive reasoning process through which he was able to learn through the course of problem solving.

We conclude from these studies that adaptiveness does not consist in the quantity or quality of knowledge acquired by these experts but in the habits of mind and dispositions that support problem solving and result in a distinctive type of reasoning process in applying knowledge to solve problems.

The Roles of Dispositions and Other Personal Characteristics in Adaptive Expertise

What enables some people to adapt and innovate and avoid detrimental over-routinization in problem solving? What motivates people to deal with ambiguity and seek alternatives to previously successful routines? Discussion among symposium participants indicated that most researchers viewed adaptiveness as involving more than domain knowledge. Adaptive experts' flexibility, innovativeness, problem-solving processes, and greater learning-through-problem-solving are understood to be supported by dispositions, habits of mind, and other personal characteristics such as willingness to take risks, to admit not knowing something, and willingness to recognize a need to change.

Certainly adaptiveness can result from greater knowledge or superior forms of knowledge, such as the acquisition of second-order rules that support application of knowledge to a greater variety of problems. Rich experience with many problem types can promote the decontextualization and generalization of knowledge. Similarly, the way that an individual learned aspects of the domain knowledge has been shown to affect the transfer and flexible use of knowledge (Bransford & Schwarz, 1999).

Further research is needed to better elaborate and understand the roles and nature of dispositions, habits of mind, and other personal characteristics in supporting adaptiveness and the development of both expertise and adaptiveness. Empirical investigation in this direction will require refinement and elaboration of the construct of adaptive expertise so that the relationships among knowledge and other personal characteristics are better specified and articulated in the context of a development model. Integration into one theoretical framework of constructs typically addressed in different fields (cognition, motivation, personality, instruction), and development of appropriate research methodologies will require interdisciplinary thinking and collaborations among researchers.

Promoting a developmental trajectory toward adaptive expertise is likely to be supported through learning experiences, such as in an approach for preparation for future learning that allows opportunity for greater decontextualization, recontextualization, and abstraction of knowledge. Experience with nonroutine problems and problems that require mastering new knowledge and innovating new problems are critical to promoting adaptive expertise (Bransford & Schwartz, 1999). Fostering dispositions and habits of mind that support knowledge building rather than just knowledge application can support the ability to change in the face of changing conditions or the inclination to seek evidence indicating whether change is needed or desirable. Understanding the nature of these personal characteristics, the conditions of their development, and their contribution to learning and adaptiveness is an important area for further research.

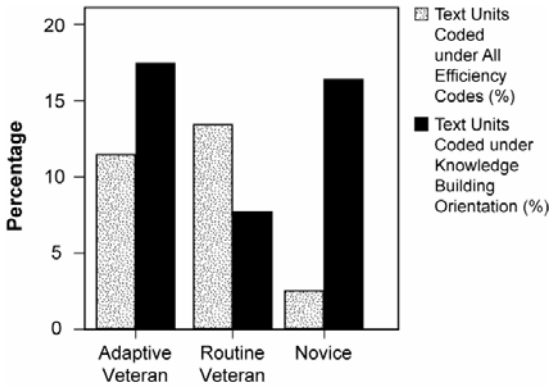
Adaptiveness in novices

Adaptiveness occurs when an individual is doing more than simply applying knowledge to routine problems, whatever the present level of knowledge is (Hatano & Inagaki, 1986). The view that adaptiveness involves more than deep domain knowledge and cognitive processes and is highly related to individuals' motivational, dispositional, and attitudinal characteristics entails the view that novices can exhibit adaptive expertise.

The concept of an adaptive novice and the characteristics of an adaptive novice require further elaboration by adaptive expertise researchers. A concept of the adaptive novice is embedded in the theory of change for adaptive expertise articulated by Schwartz et al, (2005). Their model describes adaptiveness as the occurrence of innovation in conjunction with the mobilization of heuristics, routines, and knowledge for any level of mastery of the heuristics.

Building on the conception set forth by Schwartz et al. (2005), the characterization of adaptiveness described in Wineburg (1998), Crawford and her colleagues (2005, in preparation) found that adaptiveness occurred in both novices and veterans, and that two groups of veterans could be distinguished, routine and adaptive veterans. In this study of adaptive expertise in biology teachers' instructional decision making, veteran teachers were categorized as adaptive experts or routine experts on the basis of their background characteristics, results of a questionnaire, and/or the researchers' knowledge of their professional practice. In addition, a group of novice teachers (in their second or third year of teaching) who has previously been involved in knowledge-oriented forms of work before starting to teach (and therefore likely to be adaptive) participated in the study. Research participants completed an authentic instructional problem-solving task using a think-aloud protocol. Analysis of the verbal protocols, which were coded for knowledge building-oriented utterances and efficiency-oriented utterances, found that while adaptive and routine veterans exhibited approximately equal amounts of efficiency, the adaptive veterans demonstrated markedly more knowledge building in the course of performing the task than did the routine veterans; routine experts exhibited little knowledge construction in the course of problem solving. The novices in this study showed a level of knowledge building equal to that of the adaptive experts. Novices, however, evinced little efficiency, having not yet mastered of the problem-solving heuristics that make problem solving efficient (see Figure 2).

Figure 2. Knowledge Building and Efficiency in Adaptive Experts, Routine Experts, and Second-Career Novice Teachers.



The view that novices can exhibit adaptiveness raises the question of how the personal characteristics comprised in the term adaptiveness contribute to learning and the development of expertise. Further theoretical elaboration of the contribution of habits of mind, dispositions, willingness to change and other personal characteristics to learning, development, and performance is another important area that for further researcher.

Focus on Learning and Development

Researchers who focus on adaptive expertise, rather than expertise *per se*, have strong orientations to understanding adaptive expertise in relation to development and learning in formal and informal contexts. With respect to learning, researchers studying adaptive expertise have particular interest in fostering individuals' effective and flexible application of the knowledge and skills acquired in formal and informal settings to real world contexts and problems for which tools and circumstances change rapidly. In addition, fostering the acquisition of knowledge through informal learning in work and other activity in real-world contexts is also a key area of interest. In comparison, most research on expertise focuses on understanding the nature of expertise and expert performance, rather than on their development.

Many symposium participants were concerned with understanding adaptive expertise as a developmental trajectory in which mastery of routines and knowledge occurs through and in conjunction with innovation, experimentation, and reflection. Participants wanted to understand how to foster individuals' flexibility and their proclivity and ability to innovate and to *build* knowledge in the course of problem solving rather than merely applying knowledge. Thus, most researchers investigating adaptive expertise seek to apply understanding of adaptive expertise to the design of learning environments and experiences to promote adaptive expertise.

A consideration of developmental trajectories of adaptiveness or flexibility points to the importance of a developmental approach to understanding adaptive expertise. Much research on expertise has found that expertise often confers a degree of routinization or automaticity of function that can impair performance and decrease the expert's flexibility to perform in changed circumstances. For example, Sternberg and Frensch (1992) found that when experts and novices were asked to play bridge with altered bidding rules, the experts' performance suffered more than the novices' performance. Similarly, in the study of radiologists described above (Raufaste et al., 1998), basic experts performed worse than novices in generating accurate diagnoses from a complex X-ray with multiple pathologies; this was the case because basic experts, who had become highly efficient and in their search for visual cues of disease, glossed over many subtle cues. In contrast, as noted above, super experts perform much better than all other groups because they maintained a high degree of deliberate, elaborated search for cues and reasoning in their process of diagnosis.

An important question, then, is how can educational experiences foster adaptiveness across the trajectory of knowledge acquisition? The two experiments described above demonstrate that novices start out with a relatively high degree of flexibility—like the bridge players mentioned above (Sternberg & Frensch, 1992). That flexibility, in fact, represents an absence of automaticity and routineness in application of the heuristics, schemas, procedures that support efficient and accurate problem solving in the given domain. As these heuristics and so forth are further mastered and consolidated, flexibility typically decreases. Thus, the heuristics and knowledge base that enable better problem solving and pattern recognition also, often, limit the individual's ability to see problems in novel ways, to recognize nonroutine aspects of problems, and to apply knowledge to novel problems.

How can this problem be overcome? One can hope that eventually, with greater exposure to a variety of problems and contexts, knowledge becomes decontextualized and abstracted, and more readily recontextualized in new problems and conditions (Patel, Arocha, & Lecissi, 2001). This will better enable the expert to transfer her knowledge effectively to novel problems and to innovate procedures rather than simply applying existing ones.

Given that few experts will have the opportunity to become "super experts" and go on to acquire adaptiveness, the question arises, What can be done to foster and maintain flexibility and other forms of adaptiveness throughout the development of expertise? Is it possible, through instruction and the design of an educational trajectory, to set someone on a developmental course toward *adaptive* expertise? When in the developmental trajectory of expertise should flexibility and other forms of adaptiveness be fostered? Is it better to wait until the primary body of knowledge and associated skills and abilities for a given domain have been acquired before promoting adaptiveness? Conversely, should adaptiveness be fostered from the beginning of the trajectory?

Such questions are key concerns for adaptive expertise researchers. Most adaptive expertise researchers take the view that adaptive expertise can be fostered by developing, along side content knowledge, the metacognitive skills, habits of mind, and dispositions, as well as forms of knowledge. Doing so would promote not only the mastery of content knowledge but also the flexible application of knowledge to novel problems and the innovation of problem-solving procedures and heuristics. To do this effectively, adaptive expertise researchers must elaborate a better conceptualization of the nature of personal characteristics involved in adaptiveness and the relationships among those characteristics and knowledge development.

Adaptive Expertise and Issues of Methodology

Investigating learning and development associated with adaptive expertise requires research designs and methods suited to the study of developmental processes (Henning & Rudinger, 1985; Siegler & Crawley, 1991). In addition, adaptive expertise requires operationalization in terms of a given domain. Developmental studies can be time- and resource-intensive; therefore, collaboration among researchers in a target domain and shared operationalizations can foster productivity in the field.

Methodology and the study of development and learning

Methodology entails the coordination of research questions, theoretical assumptions and frameworks, and theory-based descriptions of a target phenomenon with appropriate empirical methods for the study of that phenomenon. The term “rigor” is often used to refer to the use of experimental controls that are critical in experimental methods involved in the generation of inferences about a population from groups of individuals involved in an experiment. However, rigor properly refers to the *appropriateness* of the empirical process used for the investigation of the research questions and target phenomenon.

A focus on learning and development in the study of adaptive expertise leads to the requirement for research designs and empirical methods that are appropriate for the study of learning and developmental processes. Although cross-sectional studies (e.g., novices vs. experts) are often used in the study of expertise, cross-sectional designs enable only inferences about development; they do not enable the direct investigation of developmental and learning processes. Variables-focused studies that use statistical methods to aggregate some measure for a group in order to make inferences about the parameters of the measure in a population are appropriate for investigating the effects of different types of instructions on learning and transfer. In addition to this experimental paradigm, other forms of investigation are also important in the study of learning processes and the structural forms of change involved in individual development (Henning & Rudinger, 1985).

The study of adaptiveness requires methods that enable researchers to observe adaptiveness as it occurs and to study the learning processes involved in it. It is likely that different aspects of adaptiveness emerge over different time scales of development. It is also likely that, because some forms of adaptiveness, in some domains, develop over longer time scales, a longitudinal research design is required to observe the developmental process. The development of other forms or aspects of adaptiveness is likely to be observable in microgenetic time scales and amenable to change using microgenetic methods (Siegler & Crawley, 1991). In designing empirical investigations of longitudinal or microgenetic change, the critical element is that the density of observations is commensurate with the rate of change of the phenomenon (Siegler & Crawley, 1991). Developmental research of this nature requires resources and time to permit the investigation of change processes at various time scales and rates of change.

Designing studies to examine learning

In studying adaptive expertise and the adaptation to novel problems and content, experiments that embed opportunities to learn, to change, or to adapt in some way are critical to eliciting the target phenomenon. Wineburg's study (1998) of adaptiveness in historians' ability to apply historical analysis to new historical contexts and questions is an example of research whose design embedded an opportunity for experts to learn new material. Wineburg found that general (i.e., adaptive) expertise was involved in a historian's learning of new content in the course of addressing the experimental task. Wineburg's study involved detailed and dense observations over time of the experts' analytical process. Similarly, Crawford and her colleagues (in preparation) devised a laboratory-based study to investigate adaptiveness in biology teachers' instructional problem solving. Their task design embedded novel content (recent research findings) related to the process of protein synthesis. They used a think-aloud protocol to examine they ways that some research participants noticed, investigated, and learned novel content—content that other participants avoided, dismissed, or only superficially examined.

Operationalizing adaptiveness

Empirical research on adaptive expertise requires operationalization of adaptiveness (and its contrasting characteristic, typically efficiency). Presentations at the symposium on adaptive expertise research demonstrated that researchers have operationalized adaptiveness in a variety of ways. One group operationalized adaptiveness as the display of "innovation framing," contrasted with "efficiency framing" in a playground design task. Another group described adaptiveness as the degree of knowledge building, contrasted with efficiency and task-completion orientation, in the course of an instructional decision-making task. One presented conceptualized adaptiveness in designs as design of processes of designing—a sort of "metadesign." In these studies, efficiency was typically used as the contrast to adaptiveness, although additional contrasts are suggested in the literature, including functional fixedness, comfort with not knowing and with taking risks, and the absence of "glossing over.

Convergence among some researchers in the field around a few well-designed tasks would help the field progress.

The Context-Embedded Nature of Adaptiveness

An important issue raised in symposium discussions is the situated nature of adaptiveness. Many discussants pointed out the way that some contexts can be supportive of adaptive expertise, whereas other contexts suppress it. For example, some organizations may have policies, practices, or cultures that reward innovation and experimentation among employees, so that people feel comfortable taking risks to achieve innovation or to develop a new procedure rather than applying an old one. At the same time, adaptiveness can be understood as the ability to attempt innovation in the face of infelicitous conditions.

The issue of problem framing is relevant to the study of adaptiveness and understanding its situated nature. Traditionally in cognitive psychology, problem framing is understood to be indicative of expertise—and individual characteristic. A culture- and context-inclusive notion of adaptiveness takes into account the ways that contexts, tools, and interactions with others are integral to psychological functioning. At the same time, individuals' levels of expertise and their habits of mind and dispositions play a role in their construction or construal of a situation, and whether and to what degree it affords innovation. Symposium discussions noted that adaptiveness can be "triggered" or not by a given problem or context, highlighting the context-specific nature of adaptive expertise. Similarly, with respect to fostering adaptiveness in organizations, rewards offered by a firm for innovation may motivate some employees to innovate but constrict the creativity of others. Cognitively, given the same potential problem space, individuals construct different functional problem spaces. Thus, context is constructed in part by the individual and in part by the tools, people, and culture embedded in the context. Thus, adaptiveness, it seems, needs to be seen to some degree as the "work" of an individual and to some degree as reflecting the "affordance" of a given problem and setting for adaptiveness. How can we know whether a given problem is likely to trigger adaptiveness in a given person or group? Elaborating the theoretical relationships between person and context in situated practice is an important aspect for advancing the conceptualization of adaptive expertise.

Evaluation of the Symposium

The symposium organizers distributed a brief questionnaire to participants to evaluate the symposium. Seventeen of the approximately 30 symposium participants completed symposium evaluation questionnaires. Participants were asked to rate the symposium on the key dimensions, on a scale of 1 (lowest) to 5 (highest). Table 2 provides the results of the symposium evaluation ratings.

Table 2. Symposium Evaluation Ratings

Question	Average Rating
1. How useful was the symposium in refining your understanding about the concept of adaptive expertise and advancing your research on the topic?	4.2
2. How useful was this symposium in making you more aware of theories and concepts that will help you further your research?	4.2
3. How useful was meeting with others who are doing the research or are interested in the topic?	4.7
4. Compared to other workshops you've been to, has this given you more or less opportunity to be actively involved?	4.0

What aspects of the workshop were most helpful?

We asked participants to tell us what aspects of the symposium they found most helpful or productive in stimulating their thinking. The most frequently mentioned items were the whole-group discussions and the comments by the consulting experts. Also mentioned were the presentations and the small-group brainstorming activities. Selected quotations from participants follow:

Discussion

- The post-talk discussions.
- Presentations and discussion.
- Great discussions.
- Spontaneous discussions/ability to adapt structure of workshop.
- Meeting different people in the field who bring diverse perspectives on the topic/Hearing about the different studies on adaptive expertise & methods for exploring it.

Comments by Consulting Experts

- Panel discussion and having outside experts come in and provide different perspectives.
- For me it was the comments and perspectives of the invited responders (i.e., Chi, Patel, Nelson).
- Specialists' point of view / presentations / working groups / meeting colleagues.
- "Outside" experts provided nice viewpoint—outside what I'd expect.

Having Focused Presentations

- The talks—less so / The discussions following the talks, which identified the bad aspects and crystallized the good ones. Helped me see the emerging central concepts.
- Presentations of research & discussions of AE construct in concrete ways around these data/research designs.
- Multiple small presentations followed by discussion / small group work.

Small Groups

- Small group work and more informal impromptu conversations
- Small group interactions with diverse thinkers

Other

- It was all excellent. The presentations followed by expert feedback were very helpful. The small group acting at the end was a useful way to review what we learned and set new goals.
- Understanding the dynamic nature of how the concept is being used will allow me to contribute to the field.
- Quality of people and their focus on collaboration facilitated productive dialogue.

Symposium Participants

Robin Adams, Purdue University
Brigid Barron, Stanford University
John Bransford, University of Washington
Sean Brophy, Purdue University
Micki Chi, University of Pittsburg
Valerie Crawford, SRI International
Drue Gawel, University of Washington
Soleste Hilberg, SRI International
Taylor Martin, University of Texas at Austin
Ann McKenna, Northwestern University
Emma Mercier, Stanford University
Susan Mosborg, University of Washington
Lawrence Neely, Stanford University
Harold Nelson, Advanced Design Institute
Timothy Kieran Omahony, University of Washington
Vimla L. Patel, Columbia University
Roy Pea, Stanford University
Tony Petrosino, University of Texas at Austin
Jessica Pierson, University of Texas at Austin
Suzanne Reeve, University of Washington
Michael Richie, Boeing Corporation
Margaret Riel, SRI International
Stephanie Rivale, University of Texas
Nora Sabelli, SRI International
Mark Schlager, SRI International
Dan Schwartz, Stanford University
David Sears, Stanford University
Vanessa Sivlha, University of Texas at Austin
Yukie Toyama, SRI International
Sashank Varma, Vanderbilt University
Nancy Vye, University of Washington
Joan Walker, Vanderbilt University

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