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Expertise-Based Training: Getting More Learners Over the Bar in Less Time

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This article introduces *expertise-based training* (XBT) as an instructional design theory that draws on the theories, findings, and methods of expertise research in order to create instructional strategies that can hasten the development of advanced learners into experts. The central tenants of XBT are: 1) Key cognitive sub-skills that underlie expert performance can be revealed through expert-novice research, 2) Instructional activities can be designed, often by repurposing expertise-novice research tasks, to systematically train key cognitive sub-skills, and 3) Targeted training of key cognitive sub-skills can hasten learners along their individual paths to expertise. XBT targets apparently "intuitive" aspects of expert decision-making, such as pattern recognition and situation awareness, with drills based on the detection, categorization, and prediction tasks used in expert-novice research. XBT contrasts with, and thus compliments, holistic instructional methods such as Problem-Based Learning and simulator-based training that are associated with professional education and training.

Keywords: Expertise; Expert performance; Expertise-based training; Situation awareness; Recognition; Pattern recognition; Recognition primed decision-making.

U.S. Airways pilot Chesley "Sully" Sullenberger dramatically displayed expertise in action when he landed his totally disabled commercial jet on the Hudson River in the middle of New York City, with no injuries to 155 passengers and crew—the first no-injury water landing in modern commercial aviation history. In the wake of the Miracle on the Hudson, a story in *New York* magazine announced that, "Sully may be the last of his kind" (Kolker, 2009). The article

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expressed concern that advances in aviation technology have made expert aviators, like the 58 year-old Captain Sullivan, essentially unnecessary. Airline safety experts say that, in the vast majority of situations, "it's better to have company men than cowboys" (Kolker, 2009, p. 35). The question is whether the newer generations of pilots would be able to handle an emergency in the air as well as Captain Sullivan, who said in a *60 Minutes* interview that, "my entire life up to that moment had been a preparation to handle that particular moment" (CBS Interactive, 2009).

Indeed, training as an Air Force fighter pilot, 30 years and almost 20,000 flight hours of commercial aviation, and experience piloting gliders obviously turned Captain Sullivan into an expert. An interesting question to pose is: What if the airline industry decided that all pilots needed to be more like Sully? What theories would learning sciences provide? What strategies could teachers, trainers, and instructional designers use to incorporate systematic "expertise training" into pre-service professional education and in-service professional development programs? In aviation, and in many other performance domains, theories of expertise and expert performance provide not only a theoretical foundation and research findings but also hint at instructional methods that can support systematic training capable of addressing the challenge of getting more learners and practicing professionals over the bar to expertise in less time.

INTRODUCTION

This article introduces *expertise-based training* (XBT) as an instructional design theory that applies the models and methods of expertise research to targeted training of cognitive sub-skills that research suggests underlie the type of rapid and largely unconscious decision-making that can appear to be "intuitive" when demonstrated by an expert[1]. Rather than being the product of innate intuition, however, the rapid and largely unconscious decision-making processes of experts are based upon distinct cognitive sub-skills such as pattern recognition and situation awareness. Thus, while the totality of expert decision-making and

[1] In the context of XBT, expertise is considered to be a stage of individual development in the guild-like sequence of novice to apprentice to journeyman to expert to master. *Expert* is defined as, "highly regarded by peers, whose judgments are uncommonly accurate and reliable, whose performance shows consummate skill and economy of effort, and who can deal effectively with certain types of rare or 'tough' cases" (Chi, 2006, pp. 22).

performance is exceptionally complex, and often idiosyncratic, key cognitive sub-skills that have been identified through expertise research are amenable to systematic training—which is the goal of XBT.

Springing from a fountainhead of chess-based cognitive psychology research in the early 1970s (e.g., Simon & Chase, 1973), the modern study of expertise and expert performance has generated theoretical models, research findings, and laboratory methods that have extensive implications for the training of expert performers in a very wide range of performance domains. XBT draws heavily on this theory of expertise and expert performance, which is most strongly associated with the work of K. Anders Ericsson. The landmark *Cambridge Handbook of Expertise and Expert Performance* (Ericsson, Charness, Feltovich, & Hoffman, 2006) joins a number of collections (e.g., Chi, Glaser, & Farr, 1988; Ericsson, 1996; Ericsson & Smith, 1991; Starkes & Ericsson, 2003) that have compiled studies of expertise and expert performance in domains including sports, music, aviation, transportation, physics problem solving, medical diagnosis, surgery, and emergency room nursing. Expertise researchers, especially in the realm of sports, have not only verified and described expertise and expert performance but have also repurposed their research methods in order to improve performance through training (Williams & Ward, 2003). This repurposing of expertise research methods into expertise training methods defines the expertise-based training approach.

Obviously, professional education reaching back to medieval guilds has involved learning experiences designed to develop learners into experts, with apprenticeship continuing in the form of residencies and internships. Modern holistic instructional methods such as cognitive apprenticeship, situated learning, and problem-based learning are also designed to lead learners to thinking more like experts. Training based on these methods emphasizes authentic, whole-task learning activities. In contrast, XBT involves *targeted* part-task instructional activities that are intended to improve developing experts' performance of particular sub-skills that have been identified by expert-novice research as differentiating expert performers from less accomplished performers. XBT's drill-like approach to training cognitive sub-skills associated with intuitive expertise complements whole-task training of decision-making, problem solving, and contextual performance (van Merriënboer & Kester, 2008).

This article first outlines the theory of expertise-based training then describes the practice of XBT, including an example of designing an XBT program in the realm of teacher education. Discussion focuses on the compatibility of XBT with instructional design theories and methods, as well as considering directions for future XBT development and research.

THEORY OF EXPERTISE-BASED TRAINING

The combined term *expertise and expert performance* that is used in the literature suggests that expertise, in the form of knowledge representation, and expert performance are distinct but related concepts. XBT is primarily concerned with expert performance, in particular, seemingly intuitive aspects of expert decision-making during performance that haven't been researched or theorized as thoroughly as have the representation and training of expert knowledge. Because of the need to represent declarative and procedural knowledge in machine language, the field of intelligent tutoring systems (ITS) has a long tradition of systematically analyzing expertise[2]. Meanwhile, systematic design of instruction (SDI) has a tradition of efficiently training large numbers of learners to levels of consistently competent performance. However, the traditions of ITS and SDI have not yet been applied to systematically representing and training the "intuitive" knowledge that underlies expert performance in domains that involve rapid and largely unconscious decision-making in dynamic performance environments.

On a conceptual level, Gary Klein's recognition primed decision-making model of intuitive expertise, which was popularized in the best-selling *Blink* (Gladwell, 2005), proposes that experts in dynamic performance environments engage in pattern-recognition behavior that leads to an initial solution occurring to them without conscious effort. The experts themselves are likely to attribute their insight to luck, instincts, or even extrasensory perception (Klein, 1998). Gerd Gigerenzer (2007) views these "hunches," "gut feelings," and "intuition" as heuristics that are a natural aspect of human cognition and refers to *intelligence of the unconscious* as a rapid process of evaluating which rule-of-thumb to use in a developing situation.

On an operational level, expertise researchers have found evidence that experts enjoy an advantage in the early detection and matching of patterns in aviation (Endsley, 2006) and in sports (Williams and Ward, 2003). Expert advantage in pattern recognition has also appeared in purely cognitive performance domains such as physics problem solving (Chi, 2006) and medical diagnosis (Norman, Eva, Brooks, & Hamstra, 2006).

Expertise researchers, as cognitive psychologists, seek to discover the underlying cognitive mechanisms of expertise and expert performance. However,

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[2] Knowledge Representation has been the topic of numerous symposia organized by the Technology, Instruction, Cognition and Learning special interest group at American Educational Research Association annual conferences and the subject of numerous articles in the *TICL* journal, notably a special issue comprising Volume 5, numbers 2, 3, and 4 (2007).

although training isn't the primary interest of expertise researchers, the theoretical models, research findings, and the laboratory methods of expertise research provide instructional designers with the instructional targets and tools for designing research-based training programs. Of particular value to the training of expertise and expert performance is the expert-novice research paradigm.

Expert-Novice Research Paradigm

Expertise-based training (XBT) leverages what we have learned from more than 35 years of expert-novice studies. As originally deployed in studies of chess expertise, the expert-novice paradigm involves comparing the performance of experts with that of less advanced performers on a representative task. Researchers typically apply constraints to performance and then manipulate aspects of the task in order to find the conditions under which the performance of experts and novices diverge and the experts display a clear advantage. In that way, researchers are able to locate specific components of expertise in performing the task. For example, in their classic chess study Simon and Chase (1973) gave expert and novice chess players a brief view of a chessboard with chess pieces arranged on it. The participants in the study, who had a blank chessboard and full compliment of pieces in front of them, then attempted to reconstruct the arrangement of pieces from the stimulus chessboard. When the arrangement of the pieces on the stimulus chessboard was taken from an actual chess match, then the expert displayed a substantial advantage over the novice in reconstructing the board. However, when the arrangement of pieces on the stimulus board was arbitrary, the expert's advantage was greatly reduced.

The chess researchers concluded that expert chess players are able to recognize patterns within meaningful arrangements of pieces and remember them as chunks of information, thereby circumventing the assumed limits of working memory. The researchers also concluded that expert advantage in chess comes not from innate traits such as memory or intelligence but from domain-specific schema that is systematically acquired through many years of practice and experience. A key question suggested by the long tail of expert-novice research, and one that drives expertise-based training, is: Are there ways to hasten the development of domain-specific schema and thereby help more learners reach levels of expertise and expert performance more quickly? Answers are found not only in the models but also the methods of expertise research.

Expertise Research Adapted to Expertise-Based Training

Sports expertise research using the expert-novice paradigm has revealed that experts in many reactive sports enjoy a distinct advantage in their ability to extract predictive information from environmental clues such as the motions of an opponent who is throwing, pitching, kicking, serving, or shooting a ball or a puck. A secondary line of research in sport science has adapted the laboratory methods used in expert-novice studies in order to create training programs that target the specific anticipatory skills revealed by research as differentiating expert performance in these complex psychomotor skills (Williams & Ward, 2003). As described by Ward, Suss, and Basevitch (this issue), the approach of repurposing expert-novice research methods for training purposes is now being extended beyond the realm of sports and into training of emergency room nurses and law enforcement officers.

Quantitative findings of laboratory-based expertise research are complimented by field-based qualitative research in the area of naturalistic decision-making, where Klein and associates (Klein, 1998) have described the decision process of experts in a variety of time-constrained performance domains as including early recognition of patterns in a performance environment and unconscious comparison with patterns derived from experience and held in memory. Together, the recognition primed decision-making model and the evidence of *trainable* expert recognition skills in sports suggest that seemingly intuitive decision-making can be targeted for systematic training (Fadde, 2009). The challenges of articulating a theory for such a training approach involve situating expertise-based training within established approaches to developing expertise, determining who the experts are to model and who the learners are to train, and devising appropriate training methods.

Whole-task and part-task training of expertise. Learners' development of intuitive expertise is implicitly addressed though situated and constructivist learning approaches that have become increasingly popular since the late 1980s. Methods such as cognitive apprenticeship, problem-based learning, case-based reasoning, and simulator-based training move learners in the direction of thinking and performing more like experts by involving them in authentic, whole tasks earlier and more often during instruction. However, while education and training are moving toward increasingly holistic methods, there is also a place for part-task practice of essential cognitive sub-skills to "supplement preponderant whole-task practice" when whole-task practice does not offer adequate repetition to develop automaticity (van Merriënboer & Kester, 2008, p. 452). Pattern recognition skills would seem to represent such sub-skills that are appropriately trained with part-task approaches within a preponderant whole-task approach.

Incorporating targeted part-task practice into whole-task learning methods can increase both the effectiveness of training and also the efficiency of instructional design and learning. Rich, authentic problems demand considerable time and effort by teachers, trainers, and instructional designers to create and also by learners to complete (Hung, Jonassen, & Liu, 2008). XBT seeks to compliment whole-task instruction by applying the efficiencies long associated with part-task training of procedures to part-task training of the cognitive sub-skills that prime expert decision-making and performance.

Identifying experts and novices. Any discussion of training expertise or expert performance must address the question of "who is an expert?" Expert-novice research studies often start with identifying experts by afforded status or level of advancement. An obvious measure of expert status is amount of experience. Among professional truck drivers, for example, a "million-miler" (one million highway miles without an accident) is afforded expert status. In aviation, flying hours are the marker of perceived expertise in pilots. However, studies have demonstrated that pilots with many times the flying hours of other pilots do not reliably perform better on simulator tasks (Endsley, 2006). As an alternative to flying hours as a determinant of expertise, researchers in aviation have developed ways of measuring the construct of *situation awareness* in pilots. Situation awareness, as a measure of ability rather than afforded status, is more predictive of performance in simulator flying than is flying hours (Endsley, 2006).

One of the key tenants of expertise research is that expertise is highly specific, not only to a particular domain—as basketball star Michael Jordan demonstrated by unsuccessfully taking up baseball in mid-career (Colvin, 2008)—but also to particular roles or jobs within a domain. The expertise of a basketball point guard, for instance, varies considerably from that of a power forward, and the expertise of a jazz piano player from that of a concert pianist. Expertise can be even more specific within an organization. A top-performing Segment Five financial advisor (FA) for *Edward Jones, Inc.* is not so much an expert financial advisor as he or she is an expert *Edward Jones* financial advisor. In addition, the FA may be expert in retirement planning, but not in estate planning. The more precise the definition of expert performance, the more defensible is the designation of experts.

Expertise researchers can also avoid becoming bogged down in questions of "who is an expert?" because the expert-novice research paradigm—in practice if not in theory—doesn't require true experts but only superior performers, and it has been shown that the people in an organization typically and reliably "know who they are" (Foshay, 2006). After identifying a group of experts, researchers then identify a comparison group of non-experts. The comparison group is seldom made up of true novices, as there are so many characteristics and skills that an expert has that a novice would not have that the comparison would not help to pinpoint key aspects of expert advantage. Indeed, in most expert-novice research studies, neither true experts (in the sense of being world-class performers) nor true novices are used. Rather, more advanced performers are typically compared to less advanced performers.

While noting that expert-novice research doesn't generally compare true experts to true novices, it is essential to the paradigm that there be a distinct difference between the two groups being compared in order to reveal areas of expert advantage. The designation of "expert" and "novice" can be fairly arbitrary. For example, a seminal expert-novice study of students at an elite music school separated the students according to their rank on music school measures of musical ability. The top half of the students was designated as "expert" and the bottom half was designated as "novice." This grouping was adequate for investigating (and confirming) the research hypothesis that accumulated practice was a better predictor than were innate traits of which group (expert or novice) the students appeared in (Ericsson, Krampe, & Tesch-Römer, 1993).

Representative tasks. After researchers have identified expert and novice comparison groups, they then devise representative tasks that are designed to reveal and measure differences between experts and novices in the processes or products of performing the tasks. These laboratory-based tasks are not whole tasks that represent the full domain performance, because whole tasks—especially in an authentic performance context—are too difficult to isolate, control, and measure. Nor do expertise researchers select identifiable steps in a procedure as representative tasks. Rather, expertise researchers identify an aspect (rather than a step) of expert performance that is thought to capture distinctly expert abilities. Typically, these are decision-making aspects of expert performance rather than skill execution aspects of performance. In sports, a differentiation is made between open skills that involve reacting to the actions of an opponent (e.g., defending the goal in hockey or soccer) and closed skills that are largely focused on executing precise movements (e.g., golf and gymnastics). Within the domain of tennis, for instance, expertise researchers have not focused on the closed skill of striking the serve but rather on the open skill of returning the serve. Within the psychomotor skill of returning serve, researchers have further focused on the *perceptual-cognitive* sub-skill of recognizing the type and direction of the serve being struck.

Having identified a performance domain (tennis), an open skill within the domain (return-of-serve), and a cognitive component of the open skill (serve recognition), researchers then devised a set of tasks that further sub-divided the target skill. Expert and novice participants were shown video displays of opponent servers depicting the view of an on-court returner—an example of the *video-simulation* method used in many sports expertise studies. In one experimental task, participants were instructed to identify the type of serve being struck (flat, twist, or slice). In a second experimental task, participants were instructed to indicate the direction of the serve to their forehand or backhand side (Singer, Cauraugh, Cheng, Steinberg, & Frehlich, 1996).

By measuring the performance of expert and novice participants on the serve-type and serve-direction tasks, the researchers were able to verify and locate the "window" of expert advantage by taking away various information sources. Information that, when removed, causes a detriment in experts' performance compared to novices is assumed to have been critical to the experts' anticipatory advantage. This *occlusion* research method consists of spatial occlusion and temporal occlusion. Spatial occlusion in serve-recognition research tasks involved masking, in various trials, the on-screen location of the ball, the tossing arm, the proximal arm holding the racquet, and the body of the on-video server. When the on-video server's proximal arm and racquet were masked, the expert participants' advantage in identifying the type of serve disappeared—thereby defining the spatial window of expert advantage. Researchers confirmed coaching convention in finding that expert tennis players focus on the proximal arm and racquet more than on the ball or the server's body (Farrow, Chivers, Hardingham, & Sacuse, 1998).

Temporal occlusion in tennis serve-recognition studies involved masking the entire video display of the on-video server by editing to black at various points in the server's motion or resulting ball flight. The expert and novice participants both performed well on the representative tasks of recognizing serve type and serve direction when any amount of ball flight after racquet-ball contact was shown. However, when the video display was occluded at the moment of racquet-ball contact, the experts had a distinct performance advantage. Researchers occluded the display earlier and earlier before the moment of contact to discover when the experts and novices were both reduced to chance guessing, thereby determining the other side of the temporal window of expert advantage.

Just as the cell separation gels created by researchers to pursue "basic" science became essential tools of biotechnology research and practice (May & Heebner, 2003), so the occlusion methods devised by cognitive psychologists to pursue basic questions about the mechanisms of expertise also provide essential methods for training expert performance. In the area of sports expertise research, some of the same researchers adapted the method of video-simulation with temporal occlusion to successfully train the serve recognition ability of intermediate tennis players (Farrow et al., 1998; Scott, Scott, & Howe, 1998). XBT is an outgrowth of these sports expertise studies that directly apply the methods of expert-novice research to training intended to hasten the development of expertise in advancing learners. Sports expertise researchers have realized for at least 15 years that this research-to-practice approach unlocks some of the most elusive aspects of expert performance (Starkes & Lindley, 1994). Ironically, the approach has yet to become a routine part of the training of expert athletes and teams. However, the approach is beginning to be applied to areas outside of sports (see Ward, Suss, & Basevitch, this issue), and the underlying principles can potentially be applied to developing expert performers in a wide range of domains. The central principles of XBT are:

1. Key cognitive sub-skills that underlie expertise and expert performance can be revealed through expert-novice research,
2. Instructional activities can be designed, often by repurposing expertise-novice research tasks, to systematically train key cognitive sub-skills of expertise, and
3. Targeted training of key cognitive skills can hasten learners along their individual paths to expertise.

PRACTICE OF EXPERTISE-BASED TRAINING

The central theoretical principles of XBT are reflected in three stages of developing XBT: identifying congnitive skills that differentiate expert performers, devising instructional activities to systematically train identified skills, and integrating expertise-based training into existing training and education programs. More detailed instructional design principles are grouped into these three stages of XBT.

Stage 1: Identifying Appropriate Sub-Skills of Expert Performance

1. XBT targets seemingly intuitive aspects of expert decision-making and performance such as pattern recognition and situation awareness.
2. XBT activities emerge from research identifying differences in the processes or the outputs of more expert and less expert performers on representative tasks.
3. XBT isn't intended for initial acquisition of knowledge or skills but rather for "next level" learning, especially the transition from skilled to expert.

Stage 2: Devising XBT Activities

4. XBT includes activities that build automaticity through repetition, immediate feedback, and progressive difficulty. In other words, drills.
5. XBT repurposes expert-novice research tasks such as *detection*, *categorization*, and *prediction* for use as training tasks.

6. XBT favors implicit rather than explicit instruction, focusing more on incremental improvement rather than on learning the mechanisms of expert performance.

Stage 3: Integrating XBT into Training Programs

7. XBT focuses on recognition sub-skills rather than whole-task performance.
8. XBT activities targeting recognition sub-skills are more amenable to delivery via Internet than activities training whole skills (e.g., simulators).
9. XBT activities compliment expertise-building instructional methods such as Problem-Based Learning and simulator-based training.

Identifying Appropriate Sub-Skills of Expert Performance

Not all domains of performance include the type of rapid and seemingly intuitive decision-making in a dynamic environment that XBT is intended to develop. Even in domains that do feature such performance, it may involve only a portion of a professional's activities. A financial advisor, for example, spends considerable time studying the various types of markets and learning about the financial products that he or she has available. The financial advisor's "theater of performance"—the time when he or she is making rapid and seemingly intuitive judgments and decisions in a dynamic environment—is the client interview. Social services professionals, journalists, mechanics, and physicians have similar theaters of performance within their overall job duties. The first stage of expertise-based training, then, includes determining if and where a domain of interest includes dynamic, decision-based performance.

The focus then turns to sub-skills of the identified performance that are typically associated with expertise and expert performance, and therefore might be targeted for expertise-based training. In studying or training complex psychomotor skills, the overall performance skill can be separated into component *production* skills and *recognition* skills (Fadde, in press). For example, in tennis the serve recognition component of the overall return-of-serve skill is a good candidate for expertise-based training approaches. The XBT principle of locating a recognition component of an open performance skill for targeted training applies in cognitive as well as psychomotor domains. For example, classroom teaching involves production skills in the delivery of a lesson and also recognition skills in monitoring student behavior and comprehension during the teaching performance. After determining that a domain of interest includes an appropriate aspect of performance, stage one of XBT continues with locating or conducting expertise research that can direct the design of an expertise-based training program.

Locating or conducting expertise research. Some domains, such as aviation and medical diagnosis, have a base of expertise research that instructional designers can draw from in devising XBT activities. Indeed, leading medical educators are giving overt consideration to applying expertise research models and methods to the creation of instructional activities for medical education programs and potentially for continuing medical education (Rikers & Vimla, 2007). However, in many domains an existing base of expert-novice research will not be readily available. An instructional designer, then, has the options of designing XBT activities based on the findings and methods of expert-novice studies in related domains, or of conducting an original "design quality" expert-novice study[3].

Conducting an expert-novice study as an instructional design strategy is similar in many ways to conducting Cognitive Task Analysis (CTA), which also adapts research methods, such as think-aloud protocol, for extracting expertise for training purposes. The amount of time provided for front-end design, the goals of the instructional program, and the scale of the instructional implementation delineate the cost/benefit decision involved in conducting CTA or expert-novice research. Both expert-novice research and CTA involve considerably more up-front design time and effort than is typical in the standard method of recruiting a subject-matter expert (SME) to consult on course content. The benefit is that both expert-novice and CTA methods extract experts' cognitive processes as well as their content knowledge.

Comparing Expert-Novice with Cognitive Task Analysis. With more than 100 types of CTA documented, it is difficult to generalize about CTA. However, the costs and benefits associated with CTA have been at least theoretically calculated (Clark, Feldon, van Merriënboer, Yates, & Early, 2008). CTA typically represents a large front-end investment in not only interviewing multiple expert practitioners but also observing the experts as they complete representative tasks, sometimes collecting and analyzing think-aloud protocol data. With estimates that experts typically are not fully aware of about 70 percent of their decisions (Feldon & Clark, 2006), costs of conducing CTA can be justified when important procedures, such as field surgery, are extracted with more detail and fewer missed steps using CTA methods than by relying on the SME method. CTA-produced training

[3] Conducting a "design quality" expert-novice study should be easier and less rigorous than conducting a "research quality" expert-novice study because of lower requirements for experimental control and analysis. The findings of a design-quality study, like user testing done to support product development, are not intended to be generalizable but only to inform instructional design decisions for a particular instructional program.

is often more consistent and more efficient in delivery, potentially saving hundreds of trainer and trainee hours (Clark et al., 2008).

Expert-novice research provides another way to advance beyond the content-oriented SME model by discovering what experts actually do during the completion of a representative task. CTA and expert-novice paradigm differ in scope, as CTA is usually intended to capture the totality of expert knowledge and is appropriate for initial learning whereas expert-novice research is narrowly focused on *differences* between experts and novices as a means of locating particular subskills that are associated with expert advantage. Training approaches derived from expert-novice research are generally not appropriate for initial learning but rather are designed for advanced learners who have largely acquired basic domain content and skills.

The benefits of conducting original expert-novice research to inform the design of XBT activities come in verifying the existence of expert advantage in the particular performance skill of interest and in improving the precision with which the skills are targeted for training. Developing research tasks to observe expert-novice differences also takes an instructional designer well down the road to designing and developing XBT activities since testing and training can be accomplished with essentially the same tasks.

Devising XBT Activities

The value of finding or conducting expert-novice research is not only in verifying the existence of expert advantage but also in refining the parameters of that advantage in order to create more precise training activities. For example, in an expert-novice study of a skill similar to tennis return-of-serve, expert baseball batters performed better than novice batters at recognizing the type of pitch being thrown by a videotaped pitcher (see Figure 1). As opposed to serve recognition, where the window of expert advantage was just before ball-racquet contact, the window of expert advantage in baseball pitch recognition was determined to be in a time frame just after release of the pitch (Paull & Glencross, 1997). The difference between the windows of expert perceptual advantage in tennis and baseball illustrates that, although the expert perceptual advantage can be theoretically modeled, expert-novice research provides the skill-specific definition to create focused and valid training drills.

A training program was developed that adopted the video-simulation/temporal occlusion method used in the expert-novice pitch recognition study in order to progressively drill college varsity baseball players to identify the types of pitches thrown by a video pitcher. Trainees started by reaching criterion pitch identification percentage at the easiest occlusion level (about 1/3rd of ball flight shown) and

FIGURE 1
Video-simulation to test and train baseball pitch recognition.

progressed to criterion at the most difficult occlusion level (video edited to black at Moment-of-Release of the pitch). Separate drills involved identifying the type of pitches thrown and predicting the location of pitches in the strike zone. Trainees successfully improved their pitch recognition ability in the video-simulation context and also improved their performance of the full batting skill in competition (Fadde, 2006).

Detection, categorization, and prediction tasks. For both research and training purposes, the sub-skill of pitch recognition was broken into two sub-skills that were measured and trained separately: Identifying the type of pitch thrown by the video pitcher (a *categorization* task) and anticipating the ultimate location of the pitch in the hitting zone (a *prediction* task). Categorization and prediction—along with *detection*—are laboratory tasks that are typically associated with expert-novice research (Chi, 2006) and that are amenable to repurposing as XBT drills. A detection task was not used in researching or training serve and pitch recognition skills in tennis and baseball because a player knows where and when an action (serve or pitch) will originate and has a limited set of alternatives to choose from, representing moderately ill structured problems. However, a detection task can be appropriate for measuring or training performance that involves more ill structured problem solving. For example, the 1–3% malignancy rate of mammograms suggests that a detection task is highly appropriate for expert-novice research or expertise-based training related to reading mammograms.

Researchers intent on measuring individual differences between experts and novices in the skill of reading mammograms, or instructors intent on training the skill, have available to them large libraries of authentic mammograms—all of which have had the diagnosis and location of any tumors validated by later surgery or by subsequent mammograms (Ericsson, 2004). A representative task devised for expert-novice research and/or expertise-based training might involve specialists (experts) and residents (novices) viewing a large number of mammograms and detecting the few that call for further scrutiny. A separate categorization task might involve experts and novices research participants, or near-expert learners, diagnosing a collection of suspicious mammograms. Indeed, a similar design was used in a landmark expert-novice study of radiology expertise (Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988).

Integrating XBT into Training Programs

After identifying appropriate cognitive sub-skills for XBT, finding or conducting expert-novice research to refine target skills, and devising training activities that are based on expert-novice research tasks, the third stage is to integrate XBT activities into existing educational or training programs. The points of entry for XBT into the preparation of experts are that it addresses the intuitive expertise associated with expert performance in many domains and that it does so in a *targeted* way. Targeted, part-task instruction can be more efficient than holistic learning for improving sub-skills, which then allows learners to advance further and faster during whole-task learning.

Targeted training of recognition skills. Traditionally, production skills are often isolated and targeted for efficient and focused initial learning and practice—sometimes referred to as *behavioral practice* (Vickers, 2007). As more modern whole-task learning methods have come to the forefront, atomistic content learning and chaining of procedural steps have been de-emphasized, in great part because of a desire to develop holistic knowledge and performance (van Merriënboer & Kester, 2008). Recognition skills are largely assumed to develop implicitly and inductively through holistic learning experiences, including student teaching and medical residencies, and whole-task instructional activities such as *decision practice* in sports (Vickers, 2007). However, the same instructional efficiencies, for both instructional designers and learners, which have traditionally been gained through targeted training of production skills can also be gained through targeted training of recognition skills. One of the key contributions of sports expertise research and training is to demonstrate that recognition and production skills that are de-coupled for targeted training can then be re-coupled during holistic practice to facilitate transfer of integrated skills to full performance (Williams & Ward, 2003).

Benefits of de-coupling production and recognition skills for separate, targeted training are demonstrated by one of the few expertise-based training programs that has been implemented with high-level, competing athletes as part of routine team practices. College varsity softball players participating in a video-simulation pitch recognition training program on a laptop computer (*Interactive Video Training of Perceptual Decision-Making*, see Figure 2) were able to "see" approximately 2,000 pitches in a program of ten 15-minute training sessions (Fadde, 2005), far more then they would encounter in a similar amount of "live" batting practice. The part-task computer-based pitch recognition training complemented

FIGURE 2
Perceptual-cognitive training of pitch recognition (softball).

traditional part-task batting activities (Figure 3) that were a routine part of pre-season, indoor practice sessions. Part-task bat swing and pitch recognition activities were later re-coupled during live batting practice and game batting performance. Although it has not been empirically verified, it seems unlikely that part-task video-simulation training that is not integrated with more holistic practice would result in transfer of learning to performance.

One implication of video-simulation training of recognition skills separate from production skills is that it can be delivered on a laptop computer, and potentially over the Internet, thus enabling a practicing professional to engage in lower-fidelity training of recognition skills in preparation for whole-task simulator-based

FIGURE 3
Psychomotor training of swing production (softball).

training. For example, police forces that send officers out of state for "use of force" (shoot/don't shoot) training on a high-fidelity simulator (McMahon, 1999) could potentially reduce the time and increase the effectiveness of simulator training by "priming" the whole-task simulator training sessions with part-task video-simulation training. The theoretical models and video-simulation methods developed in sports expertise research have especially significant implications for training of perceptually based decision skills in military contexts (Ward, Farrow, Harris, Williams, Eccles, & Ericsson, 2008).

The operational principle of part-task training of recognition as well as production skills within a program of predominantly whole-task learning extends beyond the types of performance associated with simulator-based training. For example, Ertmer and Stepich (2005) have modeled the instructional design process as consisting of *problem finding* (recognition skills) and *problem solving* (production skills) stages, and have conducted expert-novice research that reveals expert advantage to be largely located in the problem finding stage (Ertmer, Stepich, York, Stickman, Wu, Zurek, & Goktas, 2008). Ertmer and Stepich (this issue) then use the findings of their expertise research studies to inform the design of curriculum and activities for professional education programs in instructional design. While problem finding skill is assumed to develop implicitly through holistic, problem-centered instructional activities, the implication of expertise-based training is that problem finding could be targeted for lower-complexity but higher repetition drill-type training in addition to, and perhaps in preparation for, whole-task practice.

The applicability of XBT approaches in performance realms outside of the psychomotor domain is illustrated in detail in the following example of designing an XBT program in the context of teacher education. The performance skill of student-centered teaching that is targeted for XBT includes a type of recognition sub-skill that is similar in many ways to the sub-skill of pitch recognition in baseball. In both cases, expertise research has revealed that largely unconscious recognition of environmental cues primes expert performers' seemingly intuitive decision making. As in sports expertise training, XBT activities designed for teacher education make use of video-based drills that use detection, categorization, and prediction tasks to train recognition skills.

EXAMPLE: Developing an XBT Program in Pre-Service Teacher Education

This example is somewhat hypothetical in that the XBT activities described have yet to be systematically applied in authentic teacher education contexts—although the same can be said for the sports expertise training approaches upon which it is modeled. However, the example serves to illustrate the three stages of developing XBT: identifying key cognitive sub-skills associated with expert performance, devising XBT activities, and integrating XBT into an established program of professional education.

Identifying Appropriate Sub-Skills of Expert Performance

In many teacher education programs, student-centered teaching is emphasized. However, there are few opportunities outside of field experience for pre-service teachers to practice the *recognition* component of monitoring student behavior and comprehension that are central to student-centered teaching. The need to train pre-service teachers' recognition skills is supported by expert-novice research showing that inexperienced ("novice") teachers suffer considerably more cognitive load when delivering classroom lessons than do experienced ("expert") teachers and, further, that the greater cognitive load impairs the novice teachers' ability both to deliver the lesson and to monitor student behavior (Feldon, 2007).

Van Es and Sherin (2002) developed the construct of *noticing* to describe teachers' ability (or inability) to pickup cues about students' learning behavior. To study teachers' noticing, the researchers used qualitative video analysis methods that involved videotaping teachers' classroom lesson presentations and then coding the video for instances and types of student-centered teaching. The researchers then repurposed this qualitative research method as a training method, creating and using the *Video Analysis Support Tool (VAST)* to have pre-service teachers code video of their own teaching activities and reorganize video segments for analysis (Sherin & van Es, 2005). Comparing reflective essays written by participants using the *VAST* system with essays written by participants in a control group who reviewed self-video but did not use *VAST*, the researchers found that video analysis activities led to more awareness of student-centered teaching issues. Similar studies have involved pre-service teachers coding self-video (Rich & Hannafin, 2008) and editing clips from self-video to post on an electronic portfolio (Fadde, Aud, & Gilbert, 2009). Although pre-service teachers have been videotaped for feedback purposes since the mid-1960s, these video editing and analysis activities are intended to increase the depth of pre-service teachers' written reflections.

The extent to which expert-novice studies of lesson teaching and research involving video analysis to improve pre-service teachers' reflection can be applied to creating training objectives and activities is a central XBT issue. Applying XBT principles suggests looking more closely at the target skill of student-centered teaching and, in particular, at the recognition sub-skills that are involved. XBT principles also lead to thinking in terms of drills, especially drills that involve detection, categorization, or prediction tasks, that can be used in a sequence of XBT activities that fit into an existing program of teacher education.

Devising XBT Activities and Program

The XBT principle of training recognition skills separately from production skills suggests isolating the recognition skill of noticing student behavior from the production skills of presenting a lesson. Eliminating the production component has an impact on the type of stimulus video used for XBT. The vast majority of classroom video is recorded for analysis by the teacher or pre-service teacher being recorded (self-video) and is recorded by a single, unattended camera that is usually focused on the teacher. Stimulus video to be used by pre-service teachers to *notice* student behaviors need not be self-video. Indeed, stimulus video showing other teachers is probably better for focusing pre-service teachers' attention on students' learning behaviors rather than their own teacher behaviors as research shows that pre-service teachers viewing self-video tend to be overly focused on their own teacher behavior even when given explicit instructions to focus on student behavior (Calandra, Gurvitch, & Lund, 2008).

The second way that focusing on student behaviors impacts the way that the stimulus video is recorded is that video used for training the recognition skill of *noticing* needs to record the pupils in the classroom, and show them close enough to perceive facial expressions, desk and group work, and student comments (Shepherd & Hannafin, 2008). This calls for a distinctly different approach to recording classroom video, which for various legal and logistical reasons, is typically recorded with a single stationary video camera located at the back of the room and focused on the teacher. Classroom video that adequately depicts student behaviors requires attaining appropriate permissions from parents and also higher video production value, possibly including multiple stationary cameras or an actively operated single camera. The cost/benefit decision for an instructional designer is whether the added cost and effort of producing stimulus video that adequately represents student learning behaviors is balanced by the stimulus video being used by many more learners than are self-video recordings of individual pre-service teachers. The XBT principle of repurposing research methods as training methods argues for adopting the higher level of video production that is typically used by researchers observing and coding authentic classroom interactions (Fadde & Rich, in press), a level of video production that is also appropriate for formal assessment of classroom teachers (Hannafin & Recesso, 2009).

Detection, categorization, and prediction tasks. Video analysis instructional activities developed and tested by researchers (Rich & Hannafin, 2008; Sherin & van Es, 2005) that involve pre-service teachers "tagging" stimulus video (a detection task) are very close to serving as XBT activities and can be further developed by using appropriate stimulus video and adding the basic drill elements of repetition, feedback, and progressive difficulty (Alessi & Trollip, 2001). A separate *categorization* task would involve having pre-service teachers code stimulus video of authentic classroom teaching (both expert and novice teachers) that is edited to concentrate many more instances of student learning behavior and teacher responses. A high-level *prediction* task might have pre-service teachers predict results on student learning behavior of the responses the teacher in the stimulus video makes, or does not make, to student behaviors.

Model-based feedback to improve expertise. With video analysis tools allowing multiple users to code the same video footage (Rich & Tripp, 2009), it is feasible to have expert and novice teachers code stimulus video in an initial design-quality expert-novice study designed to verify and refine expert advantage in *noticing* and then to use the experts' coding to provide model-based feedback (see Ifenthaler, this issue) during instruction. Although conceived of in the context of intelligent tutoring systems, the approach of extracting expert judgment and almost automatically repurposing it as expert model-based feedback within the same video analysis tool has many instructional design advantages. First, it extracts expertise in the context of experts performing a representative task—a method used by Cognitive Task Analysis as well as by expert-novice research. Second, it packages the extracted expertise essentially without an instructional designer being required to make expert judgments. Third, it supports an implicit learning model by which pre-service teachers induce at least a "starter schema" for the seemingly intuitive ability of expert teachers to notice student learning behaviors and unconsciously determine which behaviors should be ignored, which monitored, and which immediately addressed through student questioning strategies.

Program of XBT activities. This example shows how XBT addresses a relatively small component of an overall performance skill, but one that is associated with expert performance and that is not generally addressed with systematic instruction. XBT would allow pre-service teachers to practice the component skill of *noticing* before engaging in whole-task, situated lesson presentation activities—a training sequence of:

1. Developing declarative knowledge by presenting concepts, principles, and strategies of student-centered teaching.

2. Developing procedural knowledge through separate practice of production skills (lesson delivery, student questioning) and recognition skills (noticing).
3. Developing integrated student-centered teaching skills through holistic lesson teaching and reflection activities.

The expectation is that *priming* pre-service teachers' noticing skill will decrease their extraneous cognitive load during lesson delivery and improve both the production and recognition aspects of student-centered teaching during holistic learning activities, thereby improving transfer of student-centered teaching into professional practice. While there are very many dimensions to expertise in classroom teaching, the application of XBT early in the learning process can potentially hasten pre-service teachers' development of the intuitive expertise that characterizes expert teachers.

DISCUSSION

The similarity between XBT activities devised for the disparate performance domains of baseball batting and classroom teaching illustrates that XBT can potentially be incorporated into training and education efforts in many and varied performance domains. In both cases, XBT focused on the recognition component of expert performance. However, looking at research in teacher education highlights the role that reflection has in the development and practice of professional teaching. Preparation for performance is also an essential aspect of expertise and expert performance, in baseball batting as well as in classroom teaching.

Preparation for performance and reflection on performance, as well as execution of recognition and production skills during performance, should eventually be included in the full expression of a theory of expertise-based training. The focus of this article has been on recognition as a component of expert performance because that is where the theoretical models, research findings, and laboratory methods emerging from expertise research (especially sports expertise research) differ most dramatically from established methods used in the training and education of experts. Targeted training of recognition skills opens a new window to systematically developing the intuitive knowledge that seems to underlie expert performance in domains that require rapid decision-making.

While it offers a distinct contrast to established methods of professional education and training, especially holistic approaches, XBT is intended as a complimentary method, filling in gaps in the preparation and development of experts. To become accepted as a routine part of professional education and training, XBT must be shown to be compatible with and to compliment established theories and methods, in particular, holistic learning approaches

Compatibility of XBT with Instructional Theories and Methods

The operational principle of XBT—that key cognitive skills which differentiate expert performers can be trained and thereby hasten the development of expertise—is compatible with, and can enhance the effectiveness of, a variety of behavioral, cognitive, situated, and constructivist methods of instruction. Case-based reasoning, for example, includes the key cognitive sub-skill of indexing stories (Jonassen, 2007)—a pattern recognition skill that would seem amenable to systematic training using XBT detection and categorization tasks. Problem solving expertise in many domains, while primarily addressed through whole-task practice, can potentially be supplemented with part-task practice that targets the essentially automatic *recurrent* stages of problem solving (van Merriënboer, Clark, & de Croock, 1996).

Focusing on routine rather than exceptional aspects of decision-making and problem solving, which experts engage in with minimal cognitive load, provides potential targets for training expertise (van Gog, Ericsson, Rikers, & Paas, 2005). In particular, the early and seemingly intuitive recognition stage of recognition primed decision-making (Klein, 1998) is a candidate for training that targets cognitive sub-skills such as pattern recognition and situation awareness (Fadde, 2009). This approach is consistent with findings from aviation research indicating that experts do not perform notably better than novices on simulator-based tasks that involve highly unusual emergency situations but rather that experts' advantage is in performing routine decision tasks with minimal cognitive load (Endsley, 2006), assumedly freeing cognitive capacity to deal with emerging emergency situations (such as losing all engines to a bird strike).

By repurposing the types of laboratory tasks used in expert-novice research, XBT favors instructional activities that are not holistic or authentic but that are optimized for consistency, repetition, and measurement—desirable qualities for training drills as well as research tasks. Such part-task activities have a complimentary role to play in the context of whole-task learning. For example, the Four-Component Instructional Design (4C/ID) model includes provision for "just in time" part-task practice within a sequence of progressively difficult authentic problems (Lim, Reiser, & Olina, 2008). Essentially, schema construction through whole-task learning can be complimented by schema automation through part-task learning (van Merriënboer & Kester, 2008).

The expertise-based training approach is also compatible with the design of intelligent tutoring systems (ITS). In particular, the method described by Ifenthaler (this issue) of extracting expertise through mapping experts' performance on representative tasks, and then transmitting expert knowledge as model-based feedback, has far-reaching implications for the training of expertise and expert performance. Both ITS and XBT seek to reduce the complex mechanisms of expertise and expert performance in order to represent expert knowledge and to train expert performance, respectively. In ITS, the reduction of intuitive expertise to heuristic rules, as suggested by Gigerenzer (2007), might be considered as a trade off between cognitive fidelity and computational efficiency (Ohlsson & Mitrovic, 2007). Similarly, XBT's reduction of intuitive expertise to training drills represents a compromise of cognitive fidelity in pursuit of instructional efficiency. In both representing expertise and training expert performance, there is a balance to be sought between fidelity and efficiency.

Future Research on XBT

The continued development of XBT as an instructional design theory depends on practitioners and researchers developing and reporting XBT implementations, with design-based research (DBR) providing an appropriate research paradigm. Although there are many interpretations of DBR methodology, Wang and Hannafin (2005) describe a DBR approach that is compatible with the theory-based, but also theory-building, goals of research on expertise-based training. This DBR approach includes:

1. Design based on theories of instruction and learning,
2. Implementation in authentic settings,
3. In-process adaptation to produce a satisfactory learning outcome,
4. Evaluation of results leading to re-design and re-implementation, and
5. Reporting of findings to inform the design decisions of other developers and to point out areas where application reveals gaps in research and theory.

Expertise-based training is, at this point, essentially an operational principle (Gibbons, 2009) that generates a plethora of design principles and instructional strategies. My hope is that teachers, trainers, human performance specialists, and instructional designers in higher education, professional education, business, military, and professional organizations will begin developing, implementing, and reporting XBT programs that are intended to hasten the progression of advanced learners into experts.

REFERENCES

Alessi, S., & Trollip, S. (2001). *Multimedia for learning: Methods and development.* Boston: Allyn and Bacon.

Calandra, B., Gurvitch, R., & Lund, J. (2008). An exploratory study of digital video editing as a tool for teacher preparation. *Journal of Technology and Teacher Education*, *16*(2), 137–153.

CBS Interactive (2009, February 8). Flight 1549: A routine takeoff turns ugly. *CBSNews.com*. Retrieved February 16, 2009, from http://www.cbsnews.com/stories/2009/02/08/60minutes/main4783580.shtml

Chi, M. T. H. (2006). Laboratory methods for assessing experts' and novices' knowledge. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 167–184). Cambridge: Cambridge University Press.

Chi, M. T. H., Glaser, R., & Farr, M. J. (Eds.) (1988). *The nature of expertise*. Hillsdale, NJ: Erlbaum.

Clark, R. E., Feldon, D. F., van Merriënboer, J. J. G., Yates, K. A., & Early, S. (2008). Cognitive task analysis. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (pp. 578–593). New York: Routledge.

Endsley, M. R. (2006). Expertise and situation awareness. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 633–651). Cambridge: Cambridge University Press.

Ericsson, K. A. (Ed.) (1996). *The road to excellence: The acquisition of expert performance in the arts and sciences, sports, and games*. Mahwah, NJ: Erlbaum.

Ericsson, K. A. (2004). Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Academic medicine*, *79*(10), S70–S81.

Ericsson, K. A., Charness, N., Feltovich, P. J., & Hoffman, R. R. (Eds.) (2006). *The Cambridge handbook of expertise and expert performance*. Cambridge: Cambridge University Press.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363–406.

Ericsson, K. A., & Smith, J. (Eds.) (1991). *Toward a general theory of expertise: Prospects and limits*. Cambridge: Cambridge University Press.

Ertmer, P. A., & Stepich, D. A. (2005). Instructional design expertise: How will we know it when we see it? *Educational Technology, 45*(6), 38–43.

Ertmer, P. A., Stepich, D. A., York, C. S., Stickman, A., Wu, X., Zurek, S., & Goktas, Y. (2008). How instructional design experts use knowledge and experience to solve ill-structured problems. *Performance Improvement Quarterly*, *21*(1), 17–42.

Fadde, P. J. (2005). Video-based simulation training of the perceptual decision-making skill of pitch recognition in the sport of softball. *Proceedings of the International Society of Sport Psychology 11th World Congress on Sport Psychology* [CD-ROM] [ISBN: 1 877040 36 3].

Fadde, P. J. (2006). Interactive video training of perceptual decision-making in the sport of baseball. *Technology, Instruction, Cognition, and Learning, 4*(3), 265–285.

Fadde, P. J. (2009). Instructional design for advanced learners: Training expert recognition skills to hasten expertise. *Educational Technology Research and Development*, *57*(3), 359–376. DOI (online first, 2007) 10.1007/s11423-007-9046-5.

Fadde, P. J. (in press). Training complex psychomotor skills: A part-task approach. In K. H. Silber & R. Foshay (Eds.), *Handbook of training and improving workplace performance. Volume 1: Instructional design and training delivery*. New York: Pfeiffer of Wiley & Sons.

Fadde, P. J., Aud, S. V., & Gilbert, S. (2009). Incorporating a video editing activity in a reflective teaching course for pre-service teachers. *Action in Teacher Education*, *31*(1), 75–86

Fadde, P. J., & Rich, P. (in press). Guerrilla video: A new protocol for producing classroom video. *Educational Technology*.

Farrow, D., Chivers, P., Hardingham, C., & Sacuse, S. (1998). The effect of video-based perceptual training on the tennis return of serve. *International Journal of Sport Psychology, 29*, 231–242.

Feldon, D. F. (2007). Cognitive load and classroom teaching: The double-edged sword of automaticity. *Educational Psychologist*, *42*(3), 123–137.

Feldon, D. F., & Clark, R. E. (2006). Instructional implications of cognitive task analysis as a method for improving the accuracy of experts' self-report. In G. Clarebout and J. Elen (Eds.), *Avoiding simplicity*, *confronting complexity: Advances in studying and designing (computer-based) powerful learning environments* (pp. 109–116). Rotterdam: Sense Publishers.

Foshay, W. R. (2006). Building the wrong simulation: Matching instructional intent in teaching problem solving to simulation architecture. *Technology, Instruction, Cognition and Learning*, *3*, 63–72.

Gibbons, A. G. (2009). The value of the operational principle in instructional design. *Educational Technology*, *49*(1), 3–9.

Gigerenzer, G. (2007). *Gut feelings: The intelligence of the unconscious*. New York: Penguin.

Gladwell, M. (2005). *Blink: The power of thinking without thinking*. Boston: Little, Brown.

Hannafin, M., & Recesso, A. (2009). *Video analysis in classroom teaching practices: Lessons learned, problems, and issues*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (pp. 578–593). New York: Routledge.

Interactive Video Training of Perceptual Decision-Making. Software program and training program design. United States Patent Office application #20070005540, assigned to Southern Illinois University, January 4, 2007.

Klein, G. (1998). *Sources of power: How people make decisions*. Cambridge, MA: MIT Press.

Kolker, R. (2009, February 9). The last aviator: Why they don't make pilots like Sully anymore. *New York*, pp. 30–35, 80–81,

Lesgold, A., Rubinson, H., Feltovich, P., Glaser, R., Klopfer, D., & Wang, Y. (1988). Expertise in a complex skill: Diagnosing X-ray pictures. In M. T. H. Chi, R. Glaser, & M. J. Farr (Eds.), *The nature of expertise* (pp. 311–342). Hillsdale, NJ: Erlbaum.

Lim, J., Reiser, R. A., & Olina, A. (2008). The effects of part-task and whole-task instructional approaches on acquisition and transfer of a complex cognitive skill. *Educational Technology Research and Development*, DOI 10.1007/s11423-007-9085-7.

May, M., & Heebner, G. (2003). Drug discover and biotechnology trends: Analysis and separation. Retrieved December 15, 2008 from http://www.sciencemag.org/products/ddbtfeb03.dtl

McMahon, P. (1999). 'Real-world' simulations keep cops sharp. *USA Today*. August 10.

Norman, G., Eva, K., Brooks, L., & Hamstra, S. (2006). Expertise in medicine and surgery. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 339–353). Cambridge: Cambridge University Press.

Ohlsson, S., & Mitrovic, A. (2007). Fidelity and efficiency of knowledge representations for intelligent tutoring systems. *Technology, Instruction, Cognition and Learning*. *5*(2), 101–132.

Paull, G., & Glencross, S. (1997). Expert perception and decision-making in baseball. *International Journal of Sport Psychology, 28*, 35–56.

Rich, P., & Hannafin, M. (2008). Capturing and assessing evidence of student teacher inquiry: A case study. *Teaching and Teacher Education*, DOI:10.1016/j.tate.2007.11.016.

Rich, P., & Tripp, T. (2009). *Video analysis tools: A conceptual framework*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Rikers, S., & Vimla, L. (2007). *Medical expertise research: A history lesson from those who wrote it*. Panel discussion at the Annual Meeting of the American Educational Research Association, Chicago, IL.

Scott, D., Scott, L.M., & Howe, B.L. (1998). Training anticipation for intermediate tennis players. *Behavior Modification*, *22*(3), 243–261.

Shepherd, C., & Hannafin, M. J. (2008). Facilitating professional development through video-based, formative assessment eportfolios. *Journal of Computing in Teacher Education*, *25*(1), 63–69.

Sherin, M. G., & van Es, E. A. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education*, *13*(3), 475–491.

Simon, H. A., & Chase, W. G. (1973). Skill in chess. *American Scientist*, *61*, 394–403.

Singer, R. N., Cauraugh, J. H., Chen, D., Steinberg, G. M., & Frehlich, S. G. (1996). Visual search, anticipation, and reactive comparisons between highly-skilled and beginning tennis players. *Journal of Applied Sport Psychology*, *8*, 9–26.

Starkes, J., & Ericsson, K. A. (Eds.) (2003). *Expert performance in sport: Recent advances in research on sport expertise*. Champaign, IL: Human Kinetics.

Starkes, J. L., & Lindley, S. (1994). Can we hasten expertise by video simulation? *Quest*, *46*, 211–222.

Van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education*, *10*(4), 571–596.

van Gog, T., Ericsson, K. A., Rikers, R. M. J. P., & Paas, F. (2005). Instructional design for advanced learners: Establishing connections between the theoretical frameworks of cognitive load and deliberate practice. *Educational Technology Research and Development*, *53*(3), 73–81.

van Merriënboer, J. J. G., Clark, R. E., & de Croock, M. B. M. (1996). Blueprints for complex learning: The 4C/ID-model. *Educational Technology Research & Development*, *50*(2), 39–64.

van Merriënboer, J. J. G., & Kester, L. (2008). Whole task models in education. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (pp. 441–456). New York: Routledge.

Vickers, J. N. (2007). *Perception, cognition, and decision training: The quiet eye in action.* Champaign, IL: Human Kinetics.

Wang, F., & Hannafin, M. J. (2005). Technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23.

Ward, P., Farrow, D., Harris, K. R., Williams, A. M., Eccles, D. W., & Ericsson, K. A. (2008). Training perceptual-cognitive skills: Can sport psychology research inform military decision training? *Military Psychology, 20*, S71–S102.

Ward, P., Williams, A. M., & Hancock, P. A. (2006). Simulation for performance and training. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 243–262). Cambridge: Cambridge University Press.

Williams, A. M., & Ward, P. (2003). Perceptual expertise: Development in sport. In J. L. Starkes & K. A. Ericsson (Eds.), *Expert performance in sports: Advances in research in sport expertise* (pp. 219–247). Champaign, IL: Human Kinetics.