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Accelerated Proficiency and Facilitated Retention: Recommendations Based on An Integration of Research and Findings from a Working Meeting

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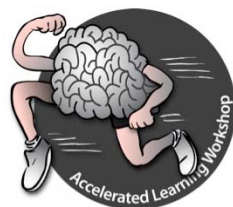
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Table of Contents

Index of Tables and Figures

Tables

Figures

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EXECUTIVE SUMMARY

TOPICS AND GOAL OF THIS REPORT

This Report deals with current issues of training:

- How to quicken the training process while maintaining its effectiveness (*Rapidized Training*),

- How to rapidize the transposition of lessons learned from the battlespace into the training context (*Rapidized Knowledge Sharing*),

- How to train more quickly to higher levels of proficiency (*Accelerated Proficiency*), and

- How to insure that training has a stable and lasting effect (*Facilitated Retention*).

In addition to a literature review, this Report integrates results from a "Workshop on Accelerated Learning" (June, 2008) and a "Working Meeting on Accelerated Proficiency and Facilitated Retention" (October, 2009), both sponsored by the Human Effectiveness Directorate and the DoD Accelerated Learning Technology Focus Team. The Workshops brought together leading academic, private sector, and DoD specialists in areas of training and expertise studies.

The goal of accelerated learning calls out an important practical tension. On the one hand is the notion that we must accelerate learning; that is, increase the rate at which highly proficient performance is achieved. On the other hand, there is a significant amount of evidence that developing expertise requires up to 10 years of experience, including practice at tough tasks (Hoffman, 1998). This suggests that it is not possible to accelerate the achievement of high proficiency. A prime goal of the DoD Accelerated Learning Technology Focus Team is to identify critical research challenges that are currently underfunded or not funded, and generate a notional roadmap for science and technology advancement.

BACKGROUND

Domain practitioners who achieve high levels of proficiency provide technical judgment to speed decision-making in time-critical events. They provide resilience to operations by resolving tough problems, acting prudently by judgment rather than by rule, and anticipating future demands with re-planning. High proficiency individuals exercise effective technical leadership in ambiguous or complex situations, often by communicating subtle features that other people will not see until they are pointed out. It typically takes years of experience for professionals to master their domain. Reasons for this include domain complexity and the need for extended and continuing practice at rare and difficult cases.

Across recent decades, many military workplaces have changed and many new ones emerged, as forms of "complex sociotechnical systems" in which the work is cognitive and collaborative, and heavily reliant on computer technology. Work in such domains requires high levels of proficiency, in terms of knowledge, reasoning skill, and critical thinking skill. Specific domains include command posts, intelligence analysis, emergency response, disaster relief, and cyberdefense. Within the military, the required preparedness status includes capabilities to be

adaptive, resilient, and robust in the face of unexpected disruptions. This is referred to as "cognitive readiness" (Morrison & Fletcher, 2002).

Critical military competencies that ordinarily take years to develop include cultural understanding, understanding and evaluation of political, cultural and economic environments of the battlespace, military implications of fused sensing and intelligence, space management for complex operations (i.e., avoiding interference), deception, influence and information operations, and campaign replanning (Joint Chiefs of Staff, 2005). The challenge of achieving and maintaining high proficiency is compounded in the military by such practices as collateral assignment, redeployment (e.g., rapid skill decay on the part of pilots creates a need for expensive re-training), inadequate or ad hoc mentoring, and the drive for "just-in-time" training.

The concept of accelerated learning was proposed in 1990 and is now a salient notion in business management and education. The phenomenon of achieving higher levels of proficiency in less time than taken in traditional training has been demonstrated in business, in teacher education, and in the training of electronics technicians. The U.S. Army's "Think Like a Commander" program and the National Training Center have demonstrated accelerated learning, as has the U.S. Navy's "Top Gun" program. A number of new DoD programs seek to achieve accelerated learning, such as the Air Force Weather Agency's "Forecast Ready" program.

Acceleration in the sense of rapidized training has also been demonstrated: The quickening of training without reduction in the proficiency level achieved at the end of the training. Indeed, indications are that rapidization methods can lead to higher levels of proficiency than legacy training.

Acceleration in the sense of achieving higher levels of proficiency has also been demonstrated, and in complex military jobs/tasks. The demonstrations all involve capturing the knowledge and reasoning of the most experienced experts, and packaging it into practice problems and scenarios. As a side benefit, the methodology behind such demonstrations also illustrate rapidized transposition of lessons learned into the training context.

LITERATURE REVIEW

One must be cautious in generalizing with regard to the effects of the numerous interacting variables that affect training. "Training for complex tasks is itself a complex task and most principles for good instruction are contextual, not universal" (Reigeluth, personal communication). Some general findings are:

Training

- Training is generally more effective if the initial learning is about domain concepts and principles rather than specific details of tasks, and procedures.
- Training at advanced levels (training to perform in dynamic and complex domains where tasks are not fixed) is generally more effective if it involves extensive practice on realistic examples or scenarios (e.g., problem-based learning).
- Training has to balance giving and withholding of outcome and process feedback to achieve optimal learning at different stages of advancement.

- Training at intermediate and advanced levels benefits significantly from experience at challenging problems or cases, the "desirable difficulties." Short-term performance might suffer, but longer-term gains will emerge.
- Mentoring is valuable and critical for advanced learning, because it provides opportunities to receive rich process and outcome feedback as learners encounter increasingly complex problems. However, mentoring is not always necessary in advanced stages of learning.
- Training using intelligent tutoring systems and serious games (virtual reality systems) can be highly effective.

Transfer

- Initial learning that is more difficult can lead to greater flexibility and transfer; when learners are initially exposed to simplifications of complex topics, serious misunderstandings can remain entrenched and interfere with or preclude deeper, more accurate understandings.

- Transferring a skill to new situations is often difficult but can be promoted by following a number of training principles: Employing deliberate practice, increasing the variability of practice, adding sources of contextual interference, using a mixed practice schedule, distributing practice in time, and providing process and outcome feedback in an explicit analysis of errors.

Retention and Decay

- There is a beneficial effect of spacing on learning and memory when the goal is long retention intervals.
- Retention is better if the same task is never practiced on successive trials, but is randomized with other practices.
- Significant decay can occur even within relatively short time frames (days to weeks) for any form of skill or learned material, including that involved in military tasks.
- The best predictor of skill retention following a hiatus is the level of performance achieved (including over-learning) prior to the hiatus.
- The variable having the largest impact on performance after a retention interval is the similarity of the conditions of testing to those of the training.
- Overlearning is the prime determinant of memory and skill decay: The greater the degree of overlearning the less decay and the less rapid the decline.

Teams
- Complex cognitive work generally is conducted by collaborations of people and technologies. Individuals who are more proficient at problem solving place a high value on cooperation and engage in more work-related communication.
- A team of experts is not necessarily an expert team. In high functioning team, the team members develop rich mental models of the goals and activities of the other team members.
- Team training must consider content knowledge, perceptual-motor skills, reasoning skills and strategies, coordination and collaboration skills, and attitudes appropriate for teamwork.

- Communication is key to process and performance. High performing teams effectively exchange information in a consensually agreed-upon manner and with consistent and meaningful terminology, and are careful to clarify or acknowledge the receipt of information.

None of the above generalizations holds uniformly; for all of the above, one can find studies showing opposite effects, or no effects. For example, while it makes sense to maintain consistency of team membership, the mixing of teams can allow team members to gain skill at helping to forge high-functioning teams. In addition, in military teams membership is often necessarily ad hoc, there is a mixture of proficiency levels, and team membership typically changes frequently.

The extensive literature on the cognition of experts provides benchmarks and standards, in terms of the defining features of individuals who achieve high levels of proficiency. The research literature also presents proven methods for scaling proficiency in terms of performance measurement. High proficiency in the military is defined by critical skills for accomplishing the mission and achieving national defense. Achieving that requires a constant 'stretching' of the skill (defined by increasing challenges), high levels of intrinsic motivation to work hard on difficult problems, practice that provides rich, meaningful feedback, and practice based on mentoring or expert instructional guidance. The rule of thumb is that it takes ten years of experience to achieve expertise. It would be highly desirable to shorten that span. If even a few years could be saved in the progression from apprentice to expert, there would be a huge savings to the military.

The fact that learning, training and instructional design are so highly complex, with multiple interacting factors, makes it impossible to compose a recipe for instructional design for proficiency training. For example, Dodd (2009) discussed the implications of moving target problems for military training and "end-to-end" evaluation. In an ideal situation, one would be able to trace the effects of instruction, from the very beginning, noting its effect across the entire span of learning various knowledge and skills, right through to final operations performance. Reasons why this is not possible include:

- The time taken for the changes due to training to percolate through to operational effects can be long and involves complex interactions with other functional realities, such as organizational constraints and operational pressures.
- There is no straightforward track, from the formal process of lessons-learned to eventual operational performance, that would enable us to give credit to any particular training factor.
- Operational outcomes are so contextually and circumstantially driven that they defy backwards-looking interpretation necessary to understand cause-and-effect linkages.
- Operational effectiveness outcomes are tied to scenarios and circumstances, making it impossible to get representative coverage permitting generalizations that specify which training inputs are effective in meeting which possible or future operational challenges.

WORKING MEETING RESULTS

In considering the meanings of accelerated learning, the Working Meeting discussions revealed a host of paradoxes that work against notions of acceleration. For example, as technology changes, as assignments change, and as jobs change, the cognitive work changes. Learning and re-learning

on the job must be continuous. But there is too much to train, in too little time. Thus, the pressure is to do Just-in-Time training, but such training is at odds with notions of proficiency training. There is a "paradox of tasks." Traditionally, training depends on componential analysis of relatively stable tasks that can be described as series of steps or procedures. But cognitive work is the context-sensitive, knowledge-driven choice among alternative activities. The traditional concept of "task" may actually be an impediment to advances in research and theory in that it reinforces an artificial notion of separability.

The most salient of the paradoxes was the practice of rotating the most highly-trained and experienced pilots to other duties and responsibilities and then sometimes rotating them back into piloting or pilot training. The actual achievement of acceleration (in any of its senses) will require serious consideration of certain organization traditions and practices. Twelve years of operational assignments is the country's return on investment for all the training, but at any time after two years at the principal piloting assignment, an individual can be moved off that career path to do something else, typically something that is not flying. Reassigning an individual just as he or she achieves high proficiency cuts against the notion that organizational capability is built upon individual expertise. Furthermore, there are practical barriers to refresher training during hiatus. In the piloting example, although there is the possibility of periodic practice using a simulator, pilots find that time constraints and duty requirements often preclude opportunities to practice.

The challenges in the military of skill decay due to hiatus assignments are not unique to the military. CEOs and senior managers can get cut off from experiences that keep them fresh, and then they make bad decisions. Discussions at the Working Meeting were anchored in specific case studies of diverse professional domains, including second language learning, power generation and coordination, weather forecasting, software engineering, STEM fields, cybersecurity, cultural awareness, personnel management, and general command. Special emphasis was placed on piloting (fighters and UAVs), in the Presentations at the Working Meeting, and a series of career interviews with experienced USAF pilots. Consensus was that the military has need for more individuals who can perform at very high levels of proficiency in all of the areas designated by COIN (counterinsurgency), DIME (diplomatic, informational, military and economic) and PIMESII (political, military, economic, social, information and infrastructure).

A number of innovative concepts were introduced at the Working Meeting, and ideas for a program of research were proposed. The Working Meeting resulted in a list of key considerations in the design of a research and technology roadmap for establishing methods of accelerated proficiency:

- Research should investigate at least two substantively different domains that have civilian analogs, relate to STEM fields, and can be treated as "open source" for getting data on baseline performance.

- Research should investigate domains with recently transformed strategic environment, where people have more than one duty assignment.

- Research must establish methods for *rapidized cognitive task analysis*. The most frequently mentioned training challenge was the pace of change in domains of professions practice, including in military jobs and specialties.

- Research needs to rely on established theories of expertise and its development, including Cognitive Flexibility Theory and Cognitive Transformation Theory, that explain how people acquire advanced knowledge, skill, ability to refine their mental models, and ability to adapt to tough cases.

- We need to be able to fine-tune training materials and strategies to the different levels of proficiency: The gap from initiate to senior apprentice, the gap from apprentice to journeyman, and the gap from journeyman to expert.

- Research needs to rely upon, but also expand upon our knowledge of what makes for a good mentor, and the most efficient and appropriate ways of using mentoring to achieve accelerated learning. We need to expand our empirical base on how to identify individuals who could become good mentors, and how to teach people how to be mentors.

- Research needs to rely the known about the features of scenarios that facilitate training, such as fidelity and pertinence to expert-level knowledge and reasoning.

The Working Meeting resulted in a list of key considerations in the design of a research and technology roadmap for establishing methods of facilitated retention:

- We need to expand our empirical base about individual difference predictors of retention, such as age, gender, cognitive ability level, education level, etc.
- We need to expand our empirical base about how periodic booster sessions (number, spacing) might affect forgetting rates.
- We need to expand our empirical base about differential decay of particular abilities. Booster training should focus on refresh of skills that would ordinarily show faster drop-off.
- We need to institute procedures for *rapidized updating* both during and post-hiatus, because during a hiatus, the missions and the technology are constantly changing.

Finally, the Working Meeting identified a number of key science and technology challenges that currently are either not funded or are underfunded:

- Understanding the requirements for expertise in military jobs and how to accelerate its attainment.

- Understanding how to increase retention of competence and proficiency.

- Developing materials and methods for accelerated learning.

- Developing technology for rapid understanding of learning and training problems (i.e., rapidized cognitive task analysis.

- Determining level of competence required for different stages of a war fighter's career.

- Determining effective ways to compress meaningful learning experiences with challenging cases.

- Calculating the cost-benefit of implementing accelerated learning.

IMPLICATIONS FOR RESEARCH AND ROADMAP

The opportunity and need is to actually track changes in job requirements longitudinally in one or more selected domains where there is a rapidly changing job environment (e.g., technology adoption issues). This would be especially pertinent with regard to the aging civilian population. Once domains of study are selected, there must commence immediately an effort to forge an appropriate proficiency scale and develop methods and measures for evaluating performance. A retrospective study should be conducted that identifies senior (or retired) experts, engages then in detailed career analysis, and captures their knowledge and reasoning skill. This Cognitive task analysis will result in work models and will support the process of creating a "library" of cases (problems scenarios, etc.) that capture expert reasoning and that can be used in training.

Research Design

Tracking performance over the ten-year span going from initiate to expert would be impractical. It would be a major project to conduct such study long enough (more than five years, realistically) to cover hiatus periods over actual careers. Nevertheless, it is precisely such study that would provide the necessary empirical base. Thus, a cohort-select design is recommended. In such a design, groups at different stages of proficiency are identified and each is tracked across their development as they progress to the next proficiency level.

Acceleration Methods

Rapidized training and accelerated proficiency can be possible through the use of computer games, simulations, and immersions, all of which are enhanced through application of intelligent tutoring and artificial intelligence capabilities.

Accelerated proficiency can be achieved through the use of case-based instruction and realistic tough cases with focus on errors and "desirable difficulties." Expertise is the source for training materials. Training for accelerated proficiency must rely upon meaningful, corrective feedback that is appropriately timed (neither too close nor too distance from the performance being evaluated).

For acceleration of team proficiency, training exercises must encourage the acquisition of teamwork skills and "people skills." Training must take into account individual differences in cognitive style and intrinsic motivation.

Accelerated proficiency and rapidized training could be achieved through "tough case time compression." Given that it takes extensive practice at difficult problems to achieve expertise, and given that tough cases are rare, a library of tough cases would make time compression possible. (This is not unlike the method of the Think Like a Commander program.) In addition to scenario and simulation-based training, additional methods for rapidization include Decision Making Exercises and Operational Simulations, both of which are specifically suited to training team decision making.

Together, the prospective and retrospective studies will allow coverage of the developmental progression greater than the five to eight year duration of the actual research project itself. They will feed into the formation of general longitudinal models. They will support an activity to calculate the costs and benefits of instituting accelerated learning methods, and the risks of not doing so.

Additional Considerations

This Report identifies some general requirements for a research program, some specific requirements in domain choice, and some methodological and measurement details that have to be refined and specified: better measures of overlearning, advances in scenario engineering technology, improved computational models of competence and proficiency, and means for measuring adaptation and resilience capacity). The Report also lists a number of opportunities to study training and hiatus effects, including studies with the U.S. Army Reserves, the Corps of Engineers, and the electric utilities. The paramount goals of a research program would be (1) Facilitating the achievement of proficiency, especially in the Apprentice to Senior Journeyman levels, (2) Retaining expertise in the form of both personnel capabilities and in the form of organizational knowledge, and (3) Result in applications to military domains including USAF mission-critical specializations.

1.0 INTRODUCTION

1.1 Background

In recent years there has been wide recognition in the business community of the importance of knowledge capture, preservation, and sharing in knowledge-based organizations. Largely this is in response to the coming "grey tsunami"—the immanent retirement of senior experts in business and government (see Hoffman & Hanes, 2003; Moon, Hoffman & Ziebell, 2009). A number of recent books, both edited and authored, both academic and popular press, have discussed the training issues and workforce challenges that have emerged as organizations have become more "knowledge-based" and technologies more pervasive in shaping complex cognitive work (e.g., Davenport & Prusak, 1998; Ericsson, 2009; Goldstein, & Ford, 2001; Kraiger, 2001; Nonaka, & Takeuchi, 1995; O'Dell & Grayson, 1998; Quiñones & Ehrenstein, 1996). The modern workplace has been dubbed "sociotechnical" in recognition of the fact that the work involves collaborative mixes of multiple people and multiple machines. Furthermore, the work is generally "cognitive work" (Hoffman & Militello, 2008). This characterizes many military work settings and missions.

Domain practitioners who achieve high levels of proficiency provide technical judgment to speed decision-making in time-critical events. They provide resilience to operations by resolving tough problems, anticipating future demands and re-planning, and acting prudently by judgment rather than by rule. High proficiency practitioners exercise effective technical leadership in ambiguous or complex situations, often by communicating subtle features that other people will not see until they are pointed out. It typically takes years of experience for professionals to master their domain. Reasons for this include domain complexity and the need for extended and continuing practice at tough cases.

As workplaces and jobs become more cognition-intensive, organizations need to take traditional notions of training to new levels, and well into the territory of complex systems. The workers in sociotechnical systems must be trained to be adaptive, so that they can cope with the ever-changing world and ever-changing workplace. People must be trained to be resilient, so that they can cope with complexity when unexpected events stretch resources and capabilities. And workers must be trained faster. Intelligent systems technology, and intelligent use of technology, will certainly play a critical role in this.

Training for the achievement of expertise has become a salient topic for discussion at research and technology meetings sponsored by all branches of the military (e.g., Hszieh, Shobe & Wulfleck, 2009). Many current military jobs (estimated at 85%) can be trained through established methods, and those jobs involve tasks that can be performed by individuals who are proficient (Wulfleck & Wetzel-Smith, 2008). In classical guild terminology, they would be "journeymen"—they have practiced to the point where they can perform their duties unsupervised (literally, they can go on a journey). The military has need for personnel who are trained at a number of levels of proficiency. While there may be some need for more Senior Experts in select areas, there is a definite and continuing need across the military for Journeymen and Senior Journeymen.

One reason is the constantly-changing nature of the sorts of missions that the military has to conduct and the various jobs involved. Furthermore, jobs must be adaptive to constantly changing threats or circumstances. In a sense, everything is getting more complex and important work is often *cognitive* work (Wulfleck & Wetzel-Smith, 2008). Research in the field of Expertise Studies has shown over and over, in diverse domains from medicine to firefighting, that it takes years of deliberate practice for individuals to master their domain, and this finding applies for many military jobs (e.g., anti-submarine warfare). Reasons why extended training and experience are required to achieve high levels of proficiency include domain complexity and the need for practice at tough cases.

Across recent decades, many military workplaces have changed, and many new ones emerged, as forms of "complex sociotechnical systems" in which the work is cognitive and collaborative, and heavily reliant on computer technology. Work in such domains requires high levels of proficiency, in terms of knowledge, reasoning skill, and critical thinking skill. Specific domains include command posts, intelligence analysis, emergency response, disaster relief, and cyberdefense. Within the military, the required preparedness status includes capabilities to be adaptive, resilient, and robust in the face of unexpected disruptions. This is referred to as "cognitive readiness" (Morrison & Fletcher, 2002).

Many current military career paths involve training to proficiency (often, high levels of proficiency) and then reassignment for some period of time (sometimes three or more years) at some other job. The classic example is that of pilot, trained to proficiency and tested in combat, and then assigned to duty at the Pentagon. Temporary reassignment is commonplace, and raises additional issues in the general area of training, specifically issues of transfer, decay, and retention of knowledge and skill.

Many organizations (e.g., DoD, NASA, the electric utilities) are at risk because of the imminent retirement of domain practitioners who are relied upon to handle the most difficult and mission-critical challenges (Hoffman & Hanes, 2003). This Report deals with current issues of training:

- How to quicken the training process while maintaining its effectiveness (*Rapidized Training*),
- How to rapidize the transposition of lessons learned from the battlespace into the training context (*Rapidized Knowledge Sharing*),
- How to train and train quickly to higher levels of proficiency (*Accelerated Proficiency*), and
- How to insure that training has a stable and lasting effect (*Facilitated Retention*).

These four concepts refer to different workforce issues, and have different implications for training research and training methodology. They are the meanings of accelerated learning are what we will refer to in this Report.

1.2 The Workshops on Accelerated Learning

A "Workshop on Accelerated Learning" (June, 2008) was sponsored by the Human Effectiveness Directorate and the DoD Accelerated Learning Technology Focus Team. The Workshop brought together leading academic, private sector, and DoD specialists in areas of training and expertise studies, to discuss the notion of accelerated learning. Presentations at that Workshop laid some of the many challenges and issues for accelerated learning.

A "Working Meeting on Accelerated Proficiency and Facilitated Retention" (October, 2009) was sponsored by the 711 Human Performance Wing, Human Effectiveness Directorate, Air Force Research Laboratory. An interdisciplinary group of participants was presented the specific task of specifying methods and research ideas for attempts to accelerate the proficiency and facilitate the retention of expertise in selected mission-critical domains. The participants were to address the following questions:

- How can we develop operational definitions and measures of proficiency at a fine grain?
- How can we develop methods for identifying expert mentors and revealing their knowledge and strategies?
- How can we best design training to promote skill retention and prevent skill decay during periods of hiatus?
- How can we train for adaptivity and the need to cope with the ever-changing workplace and changing and challenging missions?
- How can we train for resilience and the need to cope with complexity when unexpected events stretch resources and capabilities?
- What USAF jobs require high levels of proficiency and have analogs in the private sector?
- How can we construct optimal strategies for mitigating at least some skill decay while warfighters are on a long term hiatus."

Responses to these questions would feed into the formulation of guidance for attempts to accelerate the achievement of proficiency.

This report integrates the following:
> (1). The results of this second Workshop,
> (2). A literature review of research and ideas on training, skill decay, and transfer, specifically with respect to concepts of acceleration, and
> (3). Recommendations and suggestions for research and applications activities.

1.3 The Challenges

The phrase "accelerated learning" became common currency over a span of just a couple of years, culminating in the popularization of this scientific concept. Indeed, there is now a web site that promotes "Seven principles of accelerated learning."
[http://www.discoverylearning.co.uk/principles/index.html]. This appears to be a course offering that is built upon some simple generalizations about memory and the brain. The only question we

might ask is, What do the course providers mean by accelerated learning? Lacking some analysis of retention/execution across a proficiency continuum, the claim would be that the course teaches about "learning."

Acceleration can always be achieved by improving training methods that are clearly lacking in structure or effectiveness. For instance, many organizations proclaim the value of "on-the-job" training (Derouin, Parrish, & Salas, 2005), but have no structured focus for the learning, inadequate plans and procedures, and inadequate management or organizational support (Stanard, et al., 2002). Acceleration in the sense of improving deficient training is not the focus of this Report.

Accelerated Learning has been defined in a number of ways (Hoffman, et al., 2009), and we focus on three of them, which we listed above. The first is "rapidized training"—the idea of training individuals to achieve some minimal level of proficiency at a rate faster than that achieved by the current or traditional training. Second, accelerated learning also refers to the idea of getting individuals to achieve high levels of proficiency at a rate faster than ordinary. This is the second meaning that we listed above. The most succinct way of saying this is to ask: "Can we turn an apprentice into an expert in less than ten years?" Third, accelerated learning also refers to the idea of making learning more immune to decay. Once trained to a high level of proficiency, how can one stabilize that level of skill?

We take each of these senses of "accelerated learning" as a challenge.

Challenge 1: Accelerated Learning in the Sense of Rapidized Training

The goal of improving training is always paramount for trainers, instructional designers, and human resources specialists. There is always a search for better methods or for improvements of existing methods. Entire organizations within the U.S. Military, and not just individual programs, have the goal of improving training through innovations such as distance learning and simulation. Each branch of the military has Commands for training, such as the Air Force's Air Education and Training Command, Army's Training and Doctrine Command, and the Navy's Naval Education and Training Command.

Recent years have witnessed a significant diversification of critical missions that the military must perform, shifting from traditional combat to counter-insurgency, emergency relief, and human terrain. New capabilities, such as Unmanned Vehicles, have changed doctrine and operations across a broad spectrum of activities. The pace of change, and not just change itself, presents new and significant challenges, which manifest as issues for training and workforce capabilities.

Rapidized training is the goal of completing a training program in less time than ordinarily taken, while achieving the same levels of performance or proficiency at the end of the training. A more stringent definition would include the additional goal of maintaining the same level retention (performance tested some time after the conclusion of the training) or even resulting in improved retention.

Rapidized training also includes the idea of speeding up the process of assimilating lessons learned, converting them into instructional materials, and applying them in the battlefield context. This goal is significant given the rapid pace at which adversaries can adapt.

Challenge 2: Accelerated Learning in the Sense of Accelerated Proficiency

"Accelerated learning" refers not only to the idea of hastening the achievement of basic-level proficiency; it reaches across the proficiency scale to the question of how to accelerate the achievement of expertise, and whether that is even possible. It is widely recognized that warfighters and teams must be trained to high levels of proficiency, even the level of expertise, because of the need for operations that rely on cognitive work and are robust, resilient, and adaptive.

- Robustness is the ability to maintain effectiveness across a range of tasks, situations, and conditions.
- Resilience is the ability to recover from a destabilizing perturbation in the work as it attempts to reach its primary goals.
- Adaptivity is the ability to employ multiple ways to succeed and the capacity to move seamlessly among them.

Experts and Senior Journeymen are individuals who achieve high levels of proficiency. Such individuals provide technical judgment to speed decision-making in time-critical events. They provide resilience to operations by resolving tough problems, anticipating future demands and re-planning, and acting prudently by judgment rather than by rule. High-proficiency practitioners exercise effective technical leadership in ambiguous or complex situations, often by communicating subtle features that other people will not see until they are pointed out.

It typically takes years of experience for professionals to master their domain. Reasons for this include domain complexity and the need for extended and continuing practice at tough cases. Fundamental to the achievement of robustness, resilience and adaptivity is the opportunity for practice at problems that stretch current competency (Feltovich et al., 1997). Professionals must acquire knowledge and reasoning skills that pertain to critical domain goals but which must be exercised in differing situations or contexts. Capability *must* transfer in this sense.

Challenge 3: Accelerated Learning in the Sense of Facilitated Retention

The challenge of achieving and maintaining high levels of proficiency is compounded in the military by such practices as collateral assignment, redeployment (e.g., rapid skill decay on the part of pilots creates a need for expensive re-training), inadequate or ad hoc mentoring, and the drive for just-in-time training. Another significant challenge is clustered around career (versus job) training, and retention. Indeed, the entire field of "knowledge management" is formed around the notion of achieving stability.

> Skill decay is particularly salient and problematic in situations where individuals receive initial training on knowledge and skills that they may not be required to use or exercise for extended

periods of time. Reserve personnel in the military, for example, may be provided formal training only once or twice a year. When called up for active duty, however, it is expected that they will need only a limited amount of refresher training, if any, to reacquire any skill that has been lost and subsequently to perform their mission effectively (Arthur, et al., 1998, p. 58; see also Wisher, Sabol, Hillel, & Kern, 1991).

1.4 The Concept of Accelerated Learning

The concept of accelerated learning was referenced by Gott (1995) in a discussion of how the acquisition of proficiency on the part of workers in sociotechnical domains is possible only after the development of rich mental models and strategic reasoning skills; that is, the apprentice who desires to achieve high levels of proficiency has to engage in difficult cognitive work.

The concept of accelerated learning was implicit in discussions of the concept of the "expert apprentice." The idea here is that knowledge management depends on having a workforce of proficient knowledge elicitors who are trained to be able to rapidly achieve the level of understanding of an advanced apprentice, minimally. Only by acquiring domain knowledge at that level can they contribute substantively to processes of capturing and preserving expert knowledge (Militello & Quill, 2007). The field of Knowledge Management has a theme of accelerated learning, which is not surprising given the business incentives to train faster and better. One goal, for instance, is to reduce "time to value" in product innovation. Indeed, the field of Knowledge Management focused on issues of learning and training. This is shown by the emergence of the roles of Chief Knowledge Officer and Chief Learning Officer, and is reflected in magazine articles having titles such as "Learning at Top Speed" (Atkinson & Barry, 2010).

The early work on "expert systems" led to the vision that organizations might create large knowledge repositories (Becerra-Fernandez & Leidner, 2008). Knowledge Management software systems differ from traditional management information systems in that Knowledge Management software tools help create the very content on which they operate. Like traditional management information systems, however, there are issues of acceptance and integration into business procedures and organizational cultures.

Over the years since Gary Klein's seminal publication on "Preserving Corporate Knowledge" (1992), numerous articles and trade books have appeared bearing such titles as: *If we only knew what we know* (O'Dell & Grayson, 1998) and *The knowledge creating company* (Nonaka & Takeuchi, 1995) (see also Allee, 1997; Brooking, 1999; Choo, 1988; Davenport & Prusak, 1998; Lambe, 2007; Leonard & Swap, 2005). All of these discuss expertise (or "core competencies"), knowledge elicitation and knowledge repositories. These books illustrate what some see as the knowledge management craze of the late 1990s, when upwards of 25 percent of Fortune 500 companies had a Corporate Knowledge Office (Pringle, 2003). Organizations such as IBM and the World Bank have made substantial investments in support of organizational knowledge capture and management. Norman Kamilkow, Editor of *Chief Learning Officer Magazine* said,

> What we saw was that there is a growing role for a chief learning officer type within enterprise-level companies . . . there is a need to have somebody focused on how to keep the skills of the corporation's work force at a high level (quoted in Pringle, 2003, p. B1).

In the Knowledge Management process, company management establishes a program whereby experts who possess valuable undocumented knowledge collaborate with a knowledge engineer. Working together, they elicit the worker's wisdom for inclusion in the organization's knowledge base. In extreme cases, such as a senior worker retiring, the individual might be retained or brought back as a consultant (Becerra-Fernandez & Leidner, 2008).

The field of Knowledge Management raises the practical problem of knowledge finding: Identifying individuals who possess knowledge that is:

1. Unique to them,
2. Critical to the organization, and
3. Tacit in the sense of being undocumented.

This has been recognized as a key to the success of Knowledge Management broadly (Gaines, 2003; Gross, Hanes, & Ayres, 2002; Hanes & Gross, 2002). Recent experience shows that is it possible and sometimes fairly easy for experts and managers, working together, to identify the unique and important knowledge areas in which a particular expert excels. Likewise, domain practitioners can readily identify those important concepts in a domain that seem to be especially difficult for others to fully comprehend (Dawson-Saunders, et al., 1990). A critical gap, however, is that a robust, general procedure for doing this has not been formulated in such a way that anyone might implement it.

Knowledge-intensive organizations rely on decision-makers to produce mission critical decisions based on inputs from multiple domains (Becerra-Fernandez, et al., 2004). The decision-maker needs an understanding of many specific sub-domains that influence the decision-making process, coupled with the experience that allows quick and decisive action based on such information (Nonaka & Takeuchi, 1995).

An additional recent awareness is that knowledge management via knowledge capture and knowledge repositories is only a part of the solution to workforce problems.

> If an organization could capture the knowledge embedded in clever people's minds, all it would need is a better knowledge-management system. The failure of such systems to capture tacit knowledge is one of the greatest disappointments of knowledge-management initiatives to date (Goffee & Jones, 2007).

What is needed are new approaches to knowledge training, in particular, a method for accelerating the achievement of high levels of proficiency. Recognition of this need is illustrated

by the many recent books that present methods for training an expert business workforce (e.g., Clark, 2008; Goldstein & Ford, 2002; Kraiger, 2002; Quiñones & Ehrenstein, 1997).

The Air Force Weather Agency has launched a program to train "Forecast Ready" forecasters possessing high-level knowledge beyond intermediate skill levels. Such forecasters are capable of using mesoscale models and remote sensing tools. Such forecasters are able to "explain the reasoning behind the forecast" (McNulty, 2005, p. 5). To make it possible for training to accelerate learning in this sense, great reliance will be placed on mechanisms of distance learning (Pagitt, 2005). "The 7th Weather Squadron is moving at lightning speed towards a new training initiative... a premier, just-in-time combat field skills training course..." (7th Weather Squadron, 2005, p. 16).

There are domains of expertise and specialization within the military that are especially strategic and therefore important from a workforce and training perspective, and to which we would ideally be able to apply methods of acceleration. An example domain is maintenance of strategic nuclear and non-nuclear strike systems. Although this domain is not a specific focus of the present Report, it does serve to highlight some issues.

Future needs for specialized skill sets required in the domain of strategic strike capabilities have been the subject of extensive study (e.g., Defense Science Board, 2006). Because of this domain's importance, and some sense of urgency on the part of the Department of Defense, forays into research on innovations in training would not be immediately helpful and therefore not prudent. On the other hand, the recommendations of the Defense Science Board speak directly to the motivation for the study of accelerated learning, including the immanent problem of a retiring generation of engineers and the concomitant loss of organizational knowledge and skill.

Despite the fact that both the Navy and Air Force have programs designed to maintain NBC strike capabilities, the DSB expressed concerns about: (1) the lack of knowledge management processes implemented across all of the pertinent organization, to identify, track and retain critical engineering skills, (2) the challenge of attracting the best students to the pertinent science and engineering disciplines, (3) the need for high levels of proficiency in order to cope with unanticipated failures requiring analysis and re-design, and (4) the need for a new generation trained for adaptation to new concepts and emerging technologies.

> "The main finding for our project is the perceived dearth of expertise, current and future, in various of these areas, particularly in the area of ballistic missiles. In addition, there is the assessment that current Human Capital Management Systems" are insufficient for identifying, tracking, and managing critical skills" (Defense Science Board, 2006).

These are the kinds of challenges to which accelerated learning should be applicable.

The four meanings of accelerated learning are captured in the Concept Map shown in Figure 1. Figure 2 is a Concept Map that describes the related challenges. (This diagram was included in the handout material for the Working Meeting.)
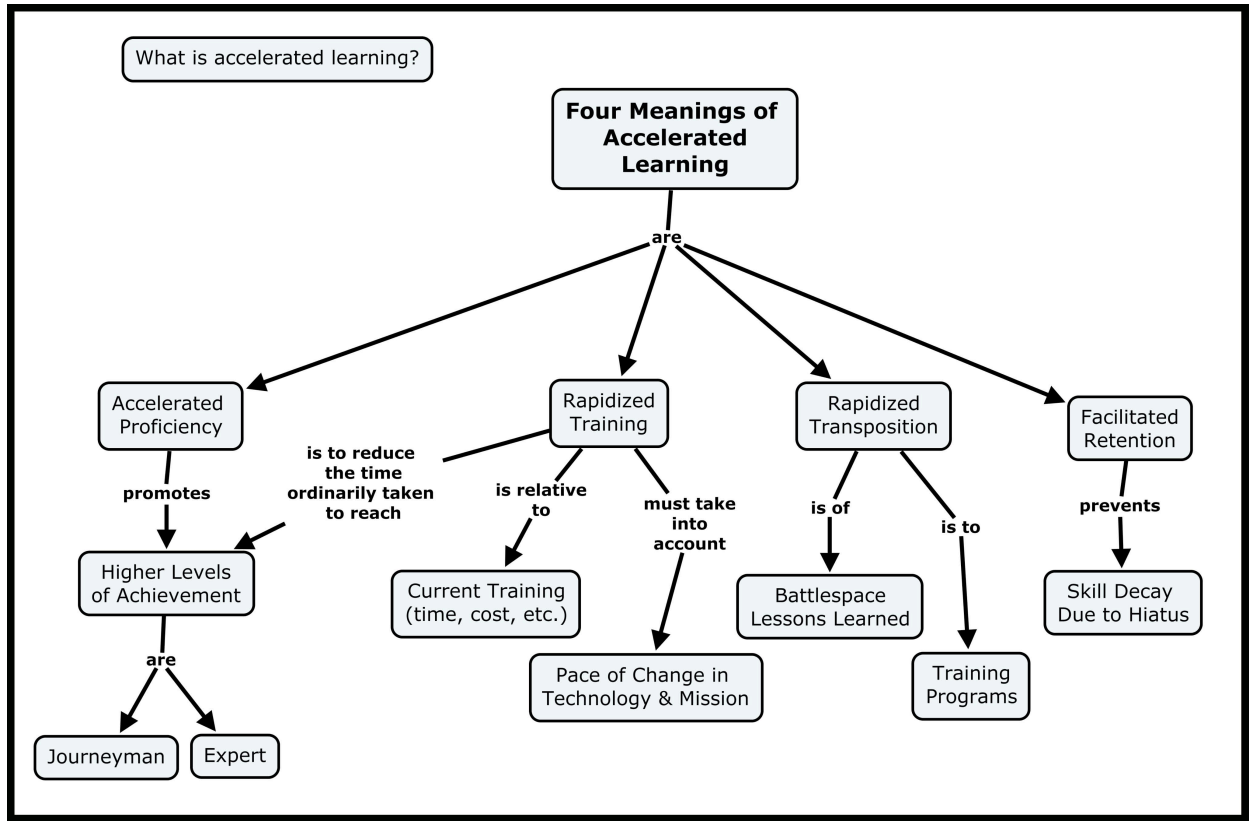
Figure 1.1. A Concept Map about Accelerated Learning
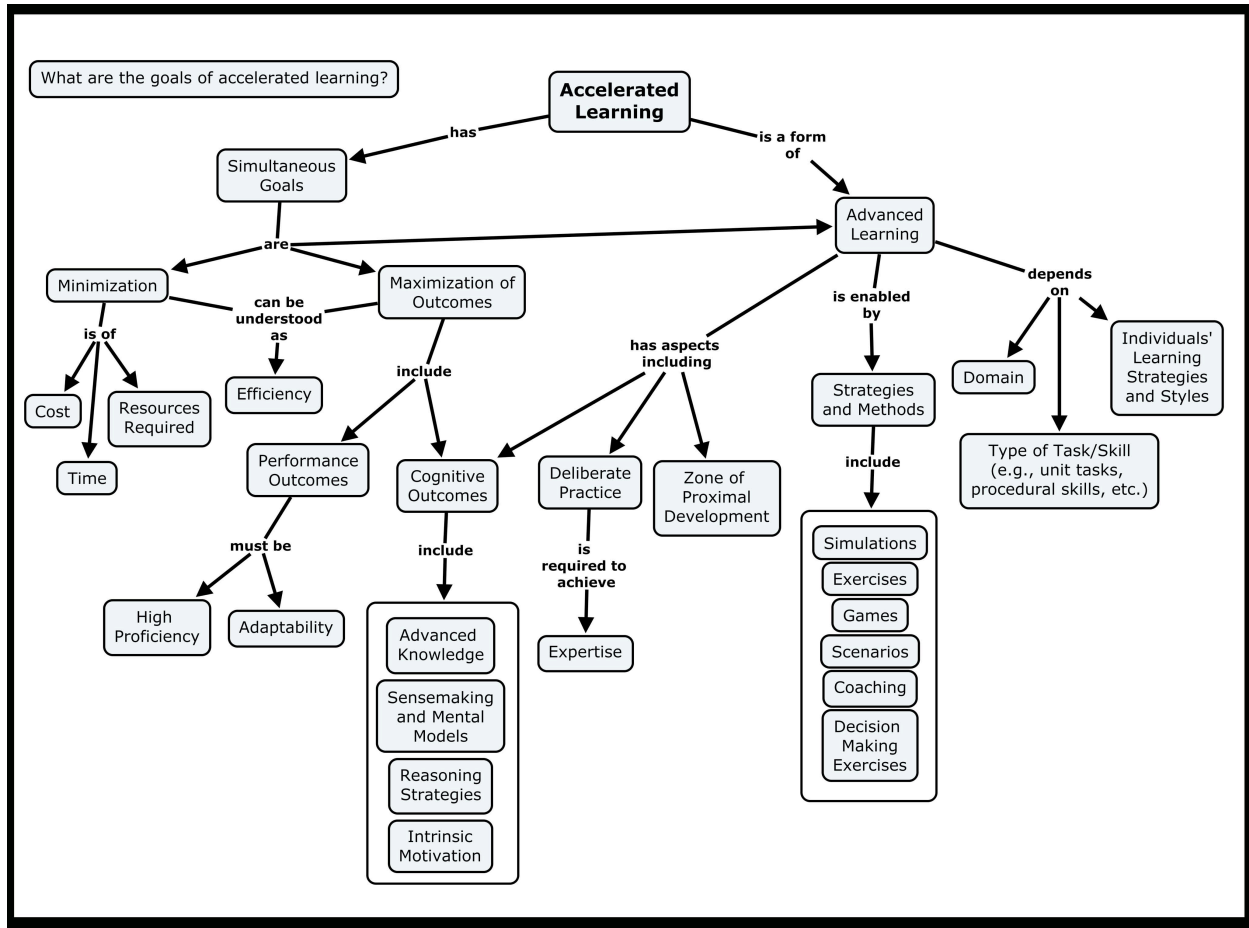
Figure 1.2. A Concept Map about the goals and challenges of Accelerated Learning.

2.0 LITERATURE REVIEW

2.1 Introduction to the Literature Review

Scientific literatures that are pertinent to accelerated learning and facilitated retention can be organized and summarized in a number of ways. One approach is to consider studies of skill versus knowledge. Another approach is to consider studies of long-term retention versus decay. One can consider studies of training in general, and military training in particular. One can consider studies of individual proficient performers or studies of teams. Cutting across all of the above, one can consider issues of measurement and evaluation.

We begin with a consideration of "types" of knowledge. This topic raises many scientific and philosophical issues, but especially issues regarding the acquisition and elicitation of knowledge (Hoffman & Militello, 2008; Carlson 2008). A distinction that is widely drawn in the literature of the learning sciences is that between declarative and procedural knowledge (as in Anderson, 2000). This distinction is slippery (concept classification an be regarded as a skill). There is a huge difference between declarative knowledge in the sense of remembering terms and concepts versus declarative knowledge in the sense of understanding complex causal relationships. There is a huge difference between procedural knowledge in the sense of stable sequences versus procedural knowledge in the sense of learning to use heuristics to achieve some goal.

Another distinction is between "memory" and "skill," with skill traditionally meaning motor skill (typified in the academic laboratory by the pursuit rotor and the typewriter). This distinction is slippery because memorization is a skill that can involve applying numerous strategies. In modern sociotechnical work systems, reasoning strategies are considered to be sets of learnable "skills" We find in this one example a need to be cautious about conceptual terminology that is laden in tradition. Complex cognitive work typically involves acting and is not merely thinking. The medical sonographer has to know how to control the sensor, the pilot has to know how to move the stick. It would be misleading to call these "motor skills" or "behaviors," since the activities are knowledge-driven, perception-driven and context-dependent.

The phrase "declarative knowledge" assumes a class of knowledge that is not declarative or not verbalizable in principle. This latter category represents an indeterminate class, sometimes called "tacit" knowledge, hiding in a philosophical hornet's nest. Thus, we might refer instead to *Teachable/Conceptual Knowledge* as knowledge that is developed by being taught or mentored and by studying training materials. *Experiential Knowledge* can be learnt only by direct personal experience—actually being there to know what it felt like. *Conjectural Knowledge/Skill* is ability at strategic sensemaking, mental projection, insightfulness, resourcefulness, opportunism and similar capabilities.

These distinctions, while slippery, are important because all generalizations about learning, retention, decay, transfer, the role of feedback, etc. regarding one type are not likely to apply directly to other types. Various combinations and degrees of the types are involved in individual sub-tasks and are admixed further in the composition of tasks and jobs. The definition of a concept can be memorized (declarative knowledge), it can be understood through comparison and contrast with related concepts (declarative knowledge), or it can be learned by classifying

examples and nonexamples (procedural knowledge). The same is true for principles (e.g. causal models) and for procedures. Memorization, understanding, and application are different kinds of learning, just as factual conceptual, procedural (steps), and causal knowledge are all very different, and all of them are required to reach proficiency in a complex cognitive task (Reigeluth, personal communication).

For further discussion of distinctions on types of knowledge and skill, see Chapter 5 in Hoffman and Militello (2008).

2.2 The Nature of Proficiency

Three topics of proficiency development are particularly pertinent to accelerated learning: The nature of high proficiency, proficiency scaling concepts and methods, and the features that make the achievement of high proficiency difficult.

2.2.1 High Proficiency

In this Report we are considering a concept of expertise referred to as "high proficiency." To accelerate proficiency, one must accelerate the acquisition of knowledge that is extensive and highly organized. One must also accelerate the acquisition of expert-level reasoning skills and strategies (Klein, et al., 2003). Thus, expertise is the "gold standard" for training, it is the source for training materials, and it is a goal for accelerated learning.

One might anchor any proficiency scale with a concept of "master." This category is used in some modern proficiency scales, such as that for chess. Simonton, (1990, 2004) has used an historiographic approach to study the progression from expert to senior expert to master in such domains as science. In some craft guilds of the middle ages, an expert was designated a master when he had created what was popularly regarded as a "masterpiece." In some craft guilds a maestro was simply the guild leader. In some craft guild traditions, a master was an expert who was elected to the council that set standards. In yet other craft guilds a "master" was any practitioner who was qualified to have apprentices. (That is, qualified specifically to be a mentor; a journeyman could be a master). Because of this polysemy, and linkage to considerations other than domain proficiency per se, we chose not to rely on the concept of master.

Research in the field of Expertise Studies has burgeoned since its inception in the mid to late 1980s (e.g., Chi, 2005; Ericsson, et al., 1981; Hoffman, 1992). (For reviews see Bereiter & Scardamalia, 1993; Ericsson, et al., 2005; Feltovich, et al., 1997).

The expert is a repository of vast historical information that enables the exercise of effective technical leadership in ambiguous or complex situations, often by communicating subtle features that other people will not see until they are pointed out. Estimates of the extent of knowledge of the average person put it at anywhere up to one million concepts (or "frames") (e.g., four new long-term memories per hour over a lifetime) (Lenat & Feignebaum, 1987). Estimates of the extent of expert knowledge put it anywhere from tens to hundreds of thousands of individual propositions (Lenat & Feigenbaum, 1987), and somewhere in the neighborhood of 50,000 concepts (or "chunks") (e.g., chess masters can purportedly recognize tens of thousands of game patterns) (Reddy, 1988; Simon & Barenfeld, 1969; Simon & Gilmartin, 1973). A review of the expert systems literature shows that some prototype systems have as few as 50 rules. However,

as many as 2,000 rules are needed even for tasks that are apparently simple, such as landuse classification. In expressing their pessimisms about the goals of AI, Dreyfus and Dreyfus (1986) asserted that simply "too many" propositions or frames would be needed to represent even a limited domain of common sense knowledge, let alone expert knowledge.

Expert knowledge is certainly extensive, and can be so extensive that even people who are regarded as "novices" can actually be very highly experienced. In the judging of livestock, for example, one might remain "novice" even after as much as ten years of experience at school and club training. Generally, those who are regarded as "experts" have 20 to 30 years of experience in domains such as livestock judging and auditing studied by James Shanteau (1988). Renowned expert aerial photo interpreters have decades of experience behind them (Hoffman, 1984). Workers in such domains naturally distinguish their peers who are good, even very very good, from the "real" experts.

Proficiency is defined not just in terms of knowledge but also in terms of reasoning strategies and skills. In one classis study, Larkin (1983) asked physics students (we would class them as initiates or apprentices) and experienced physicists to solve mechanics problems involving levers, weights, inclined planes, pulleys, forces, etc. The results of a number of such studies have shown that the basic reasoning operations or strategies (deduction, induction, goal decomposition, etc.) are applied in different orders and with different emphases for experts versus non-experts. In the initial stages of problem solving, experts spend proportionately more time than students in forming a conceptual understanding of the problem. Experts generate representations that are conceptually richer and more organized than those of the students. Students tend to use hastily-formed "concrete" (that is, superficial) problem representations whereas experts use "abstract" representations that rely on "deep" knowledge," that is, imaginal and conceptual understanding of functional relations and physical principles that relate concepts (in the case of the research on experts at mechanics, principles such as conservation of energy). Furthermore, experts are better able to gauge the difficulty of problems and know the conditions for the use of particular knowledge and procedures (for example, if there is acceleration, use Newton's second law) (Chi et al., 1982).

One widely cited rule of thumb is that the development of high proficiency takes at least ten years (Hayes, 1985). Another rule of thumb is 10,000 hours of practice or engagement with a task. (Ten years at a full time job would be about 20,000 hours, assuming that in an eight hour work day the typical worker spends about half their time engaged in their fundamental task work.) These rules are admittedly approximate and there is considerable variation across domains (Hoffman & Militello, 2009).

It is obvious that mere time in grade does not enable just anyone to qualify as an expert. A person may achieve journeyman status, become demotivated, and stay at that level for the rest of their career. To achieve high proficiency in the military there needs to be:

- Critical skills for accomplishing the mission and achieving national defense,
- A constant 'stretching' of the skill, defined by increasing challenges (tough or rare cases),
- High levels of intrinsic motivation to work hard, on hard problems,
- Practice that provides rich, meaningful feedback,
- Practice based on mentoring or expert instructional guidance.

This was termed "practice with zeal" by Edwin Thorndike (1912), one of the founders of educational psychology who focused on classroom learning and the learning of simple tasks.

More recently, it has been termed "deliberate practice" by Ericsson (e.g., Ericsson, et al., 2006) with reference to such skills as in music and chess. But the notion also holds for such domains as science, weather forecasting, engineering, piloting, and military command (Hoffman, 2007). The journeyman is one who has practices until he can reliably get it right. Achievement at that level can be accomplished by repetition. The expert practices until he can't get it wrong. Mere repetition is not sufficient for that. What is necessary is practice that systematically engages the learner in increasingly challenging ways.

The key features of High Proficiency are listed in Table 2.1.

Table 2.1 Some features of high proficiency.

• The expert is highly regarded by peers.
• The expert's judgments are accurate and reliable.
• The expert's performance shows consummate skill and economy of effort.
• For routine activities, experts display "automaticity" in which conscious processing is bypassed and the expert seems to be carrying out a task without significant cognitive load.
• The expert possesses knowledge that is fine-grained, detailed, and highly-organized.
• The expert knows that his knowledge is constantly changing and continually contingent.
• The expert forms rich mental models of cases or situations, to support sensemaking and anticipatory thinking.
• The expert is able to create new procedures and conceptual distinctions.
• The expert is able to cope with rare and tough cases.
• The expert is able to effectively manage resources under conditions of high stakes and high risk and high stress.
• Typically, experts have special knowledge or abilities derived from extensive experience with sub-domains.
• The expert has refined pattern perception skills and can apprehend meaningful relationships that non-experts cannot apprehend

When an expert approaches a familiar problematic situation, their responses do not tend to be from an analytical or deliberative process as is the case for non-experts (Frensch, 1988). Rather, an organized set of memories drawn from extensive experience forms schemas or mental models (Gentner & Stevens, 1983), which give meaning and structure to familiar repeatedly encountered problem sets. These schemas provide intuitive, immediate cognitive frameworks to help understand the nature of the problem, derive potential solutions, and anticipate constraints (Reimann & Chi, 1989). In Recognition-Primed Decision Making, the recognition of case typicality provides intuitive, immediate sensemaking frameworks to help understand the nature of the problem, derive potential solutions, and anticipate constraints (Klein, 1989; Oliver & Roos, 2005). In addition, experts are able to recognize aspects of a problem that make it novel or unusual, and will bring special strategies to bear to solve "tough cases."

What about criteria for high proficiency for military domains? It is generally assumed that expertise is valuable for the military, but how can we know? Casual observation suggests that the factors noted in the academic literature that characterize expertise are also observed in highly accomplished members of the armed services: Self-assessment and self-directed learning, deliberate practice, self-awareness of the development toward expertise, and so forth (Fletcher, 2009). Success at conducting military operations is the ultimate criterion against which these components have to be assessed. As is true for expertise in general, greater intelligence is related to better performance on military tasks, but high intelligence is not a prerequisite for the

achievement of proficiency of expertise (Ceci & Liker, 1986; Lafrance, 1989). For military jobs, as is true for expertise in general, there is mixed evidence that increased experience alone is related to improved performance (Fletcher, 2009). Rather, success seems to be related to such additional factors as cognitive flexibility, team composition, and practice, especially deliberate practice.

2.2.2 Proficiency Scaling Concepts and Methods

The analysis of proficiency and proficiency scaling can usefully commence by distinguishing experts (high and very high proficiency) from novices (very low proficiency). In the psychological and educational research literatures, expertise has defined by the contrast with novices. Research on expertise is usually premised on experimental designs have these two basic proficiency groups as the main comparison (experts vs. novices as the main independent variable) (cf. Lajoie, 2003). However, there is considerable variation in tacit definitions of "novice." For example, in a study of expert-novice differences, Chi, Hutchinson, and Robin (1988) relied on the participation of an avid dinosaur fan who happened to be a young child. In a similar developmental study, Means and Voss (1985) relied on the participation of preschool children who were avid fans of the "Star Wars" films. In many academic studies, college students have served as experts because of their knowledge of particular domains (e.g., football, wedding apparel, regional geography). In some studies of expertise in the solving of mechanics problems, graduate students have been the experts. In research on expertise in computer programming, an "expert" can be someone who has taken a few courses, and would therefore properly be called an apprentice) (Mayer, 1988).

Technically, a novice is a person who has begun an introductory course of instruction. Unlike a "naïve," who is a person who may not even know that the domain exists, the novice is the individual who has committed to a course of training.

Many studies have revealed various strategies and heuristics that experts create and rely upon (Hoffman, 2007; Lajoie, 2003). This clearly distinguishes higher from lower levels of proficiency. When presented with domain problems, novices and apprentices tend to rely on superficial features and rote procedures whereas more proficient individuals apprehend the underlying relational structure, the constraints, and the pertinent principles (Carlson, 1990; Chi, Glaser, & Rees, 1982; Egan & Schwartz, 1973; Larkin, 1981; Reed, Dempster, & Ettinger, 1985). Experts engage in rapid apprehension of cases and paths to solutions, whereas novices engage deliberate processing (Frensch, 1988).

The assumption of proficiency scaling is that across the developmental continuum there are qualitative shifts (Dreyfus & Dreyfus, 1986; Lajoie, 2003). "The knowledge of novices is not simply an incomplete version of the knowledge of the expert or mature learner, it is qualitatively entirely different" (Cazden, 1976, p.320).

The literature of Expertise Studies includes many discussions of the notion of "automaticity" (James, 1890), which is the idea that knowledge or skill undergoes a "declarative-to-procedural shift" or becomes "routinized" (Anderson, 1987). In a number of cognitive theories, developmental levels are defined entirely in terms of the development of automaticity and a reliance on implicit knowledge, that is, procedural knowledge and perceptual skills rather than explicit or declarative knowledge (e.g., Benner, 1984; Charness & Campbell, 1988; Dreyfus & Dreyfus, 1986; Fitts, 1964; Fitts & Posner, 1967; Gordon, in press; Norman, 1987; Rasmussen,

1986). Dreyfus and Dreyfus (1986; Dreyfus, 1989) proposed a five-level theory that focuses exclusively on the development of "intuition" (i.e., non-verbalizable procedural knowledge and metaknowledge), which they regard as the essence of proficiency.

Most such theories have levels such as those presented in Table 2.2.

Table 2.2. Levels of proficiency (after Dreyfus & Dreyfus, 1986).

Level One. Practitioners at this level have knowledge that is declarative or propositional, their reasoning is said to be explicit and deliberative. Problem solving focuses on the learning of facts, deliberative reasoning, and a reliance on general strategies.
Level Two. The declarative knowledge of practitioners at this level has become procedural and domain-specific. They can automatically recognize some problem types or situations.
Level Three. At this level, procedures become highly routinized.
Level Four. These practitioners are proficient and have a great deal of intuitive skill.
Level Five. Practitioners at this highest level can deliberately reason about their own intuitions and generate new rules or strategies (what Dreyfus and Dreyfus call "deliberative rationality").

The essence of all such theories is the notion that reasoning or knowledge originates as an analytic, conscious, deliberative, step-wise process, and evolves into rapid, automatic, non-conscious, understanding or immediate perceptual judgments. Many researchers in psychology and education have noted what seems to be a natural developmental sequence from superficial understanding, to a semantic understanding, and finally to a qualitative understanding (Van Lehn, 2009).

We rely on a modern variation on the classification scheme used in the craft guilds (Renard, 1968), presented in Table 2.3.

Table 2.3. Basic proficiency categories based on the traditional craft guild terminology (adapted from Hoffman, 1998).

NAIVE	One who is ignorant of a domain.
NOVICE	Literally, someone who is new—a probationary member. There has been some ("minimal") exposure to the domain.
INITIATE	Literally, someone who has been through an initiation ceremony—a novice who has begun introductory instruction.
APPRENTICE	Literally, one who is learning—a student undergoing a program of instruction beyond the introductory level. Traditionally, the apprentice is immersed in the domain by living with and assisting someone at a higher level. The length of an apprenticeship depends on the domain, ranging from about one to 12 years in the craft guilds.
JOURNEYMAN	Literally, a person who can perform a day's labor unsupervised, although working under orders. An experienced and reliable worker, or one who has achieved a level of competence. It is possible to remain at this level for life.
EXPERT	The distinguished or brilliant journeyman, 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. Also, an expert is one who has special skills or knowledge derived from extensive experience with subdomains.
MASTER	Traditionally, a master is any journeyman or expert who is also qualified to teach those at a lower level. Traditionally, a master is one of an elite group of experts whose judgments set the regulations, standards, or ideals. Also, a master can be that expert who is regarded by the other experts as being "the" expert, or the "real" expert, especially with regard to sub-domain knowledge.

Proficiency scaling is the attempt to forge a domain- and organizationally-appropriate scale for distinguishing levels of proficiency. Some alternative methods are described in Table 2.4.

Table 2.4. Some methods that can contribute data for the creation of a proficiency scale.

METHOD	YIELD	EXAMPLE
In-depth career interviews about education, training, etc.	Ideas about breadth and depth of experience; Estimate of hours of experience	Weather forecasting in the armed services, for instance, involves duty assignments having regular hours and regular job or task assignments that can be tracked across entire careers. Amount of time spent at actual forecasting or forecasting-related tasks can be estimated with some confidence (Hoffman, 1991).
Professional standards or licensing	Ideas about what it takes for individuals to reach the top of their field.	The study of weather forecasters involved senior meteorologists US National Atmospheric and Oceanographic Administration and the National Weather Service (Hoffman, Coffey, & Ford, 2000). One participant was one of the forecasters for Space Shuttle launches; another was one of the designers of the first meteorological satellites.
Measures of performance at the familiar tasks	Can be used for convergence on scales determined by other methods.	Weather forecasting is again a case in point since records can show for each forecaster the relation between their forecasts and the actual weather. In fact, this is routinely tracked in forecasting offices by the measurement of "forecast skill scores" (see Hoffman & Trafton, forthcoming).
Social Interaction Analysis	Proficiency levels in some group of practitioners or within some community of practice (Mieg, 2000; Stein, 1997)	In a project on knowledge preservation for the electric power utilities (Hoffman & Hanes, 2003), experts at particular jobs (e.g., maintenance and repair of large turbines, monitoring and control of nuclear chemical reactions, etc.) were readily identified by plant managers, trainers, and engineers. The individuals identified as experts had been performing their jobs for years and were known among company personnel as "the" person in their specialization: *If there was that kind of problem I'd go to Ted. He's the turbine guy."*

A proficiency scale for a given domain should be based on more than one of the four general types of method listed in Table 2.4, and ideally should be based on at least three. This has been referred to as the "three legs of a tripod" (Hoffman, Ford & Coffey, 2000; Hoffman & Lintern, 2006).

Social Interaction Analysis, the result of which is a sociogram, is perhaps the lesser known of the four kinds of methods. A sociogram, that represents interaction patterns between people (e.g., frequent interactions), is used to study group clustering, communication patterns, and workflows and processes. For Social Interaction Analysis, multiple individuals within an organization or a community of practice are interviewed. Practitioners might be asked, for example, "If you have a problem of type x, who would you go to for advice?" or they might be asked to sort cards bearing the names of other domain practitioners into piles according to one or another skill dimension or knowledge category.

It is important to create a scale that is both domain and organizationally-appropriate, and that considers the full range of proficiency. In the project on weather forecasting (Hoffman, Coffey & Ford, 2000), the proficiency scale distinguished three levels: experts, journeymen, and apprentices, but each of these was further distinguished by three levels of seniority, up to the senior experts who has as much as 50,000 hours of practice and experience at domain tasks.

Although mere years of experience does not guarantee expertise, there is a partial linkage in that the longer the career the greater the opportunity for more experience, and more diverse experiences. Experience scaling can also involve an attempt to gauge the practitioners' breadth of experience—the different contexts or sub-domains they have worked in, the range of tasks they have conducted, etc. Deeper experience (i.e., more years at the job) affords more opportunities to acquire broader experience. Hence, depth and breadth of experience should be correlated. But they are not necessarily correlated, and so examination of both breadth and depth of experience is always wise. Thus, one comes to a resolution that age and proficiency are generally related, that is, partially correlated. This is captured in Table 2.5.

Table 2.5. Age and proficiency are partially correlated.

	LIFESPAN					
	10	20	30	40	50	60
NOVICE	Learning can commence at any age → → (e.g., the school child who is avid about dinosaurs; the adult professional who undergoes job re-training).				Achievement of expertise in significant domains may not be possible	
INTERN & APPRENTICE	Individuals less than18yrs of age are rarely considered appropriate as Apprentices	Can commence at any age → → →			Achievement of expertise in significant domains may not be possible	
JOURNEYMAN		It is possible to achieve journeyman status (e.g., chess, computer hacking, sports)	Is typically achieved in mid- to late-20s, but development may go no further			
Expert Stage		It is possible to achieve expertise (e.g., chess, computer hacking, sports)	Most typical for 35 yrs of age and beyond			
MASTER STAGE		Is rarely achieved early in a career	It is possible to achieve mid-career	Most typical of seniors		

In the proficiency scaling in weather forecasting, Hoffman, Coffey and Ford (2000) conducted interviews, sociometric analysis and performance evaluation at a U.S. Navy weather forecasting facility situated at an airfield. By comparison of the forecasts with forecast verification data, it was possible to scale performance. By detailed analysis of personnel records (duty and duty assignments), it was possible to estimate hours spent at forecasting-related activity. Through sociometry and career interviews it was possible to gauge depth and breadth of experience. Depth of experience (number of hours) was compared to breadth of experience, as indicated by the variety of experiences possible—forecasting while at sea, experience in more than one climate, and so on. The expectation was that depth of experience (number of hours) would be verified by

breadth (variety) of experience, if only because longer experience affords more opportunities for a greater variety of experiences. By using these combined methods, the researchers converged on a proficiency scale that included levels (expert, journeyman, apprentice) and sub-levels (e.g., junior, senior). Table 2.6 describes the skill factors definitive of each level in the scale.

Table 2.6. Skill factors forming a proficiency scale appropriate to U. S. Navy forecasting.

	APPRENTICE	**JOURNEYMAN**	**EXPERT**	**SENIOR EXPERT**
PROCESS	Forecasting by extrapolation from the previous weather and forecast and by reliance on computer models.	Begins by formulating the problem of the day but focuses on forecasting by extrapolation from the previous weather and forecast and by reliance on computer models.	Begins by formulating the problem of the day and then building a mental model to guide further information search	Begins by formulating the problem of the day and then building a mental model to guide further information search
STRATEGY	Reasoning is at the level of individual cues within data types	Reasoning is mostly at the level of individual cues, some ability to recognize cue configurations within and across data types	Reasoning is in terms of both cues and cue configurations, both within and across data types. Some recognition-primed decision-making occurs	Process of mental model formation and refinement is more likely to be short-circuited by recognition-primed decision-making skill

For purposes of this Report we must repeatedly regain focus on a proficiency scale beginning at the apprentice level and including the intermediate journeyman category, and a scale in which the category of "novice" as —a person who knows next to nothing about a domain—is not nearly as pertinent as the concept of the junior journeyman. In a review of the literature of expertise studies written in 1999, Hoffman et al. said:

> Relatively little research has looked at the midrange—the distinctive qualities of apprentice-level and journeyman-level individuals (Bereiter & Bird, 1985; Campbell, Brown, & DiBello, 1992; Glaser, 1976; Mayer, 1988). Some exceptions are Means and Voss's (1985) study of the development of knowledge about the "Star Wars" films, with participants spanning ages 7 to 19 years, and Myles-Worsley, Johnston, & Simon's (1988) study of initiate (student) and journeyman (intern), and well as expert (resident) radiologists (Ch. 3.)

This statement is still true.

2.2.3 What makes the Achievement of High Proficiency Difficult?

Studies that have attempted to create domain-appropriate proficiency scales (e.g., Ericsson, et al., 1993; Hoffman, et al., 2002) have shown that the amount of practice is the single greatest determinate of superior expertise, followed by specificity of practice and deliberateness of practice to task performance (Schmidt & Lee, 2005; Ericsson, 2003). Expertise is achieved only after working hard, on hard problems (Eccles, et al., 2009). For instance, in the field of continuing education it is recognized that the progression to proficiency depends on practice at difficult tasks. Valkeavaara (1999) interviewed a group of highly experienced workers in the field of human resource management to reveal the features of problems that made them difficult. The semi-structured interviews confirmed that the best "lessons learned" were in situations that placed new demands on the worker.

Research by Paul Feltovich, Rand Spiro (Working Meeting Participants) and their colleagues on expert-novice differences in domains of medicine investigated how people deal with difficult, challenging cases (e.g., Feltovich, Spiro, & Coulson, 1989; Feltovich, Coulson, & Spiro, 2001). That research identified characteristics of problems that cause cognitive difficulty for learners, but not for experts. It also revealed how people respond to these elements of difficulty in learning and in the application of knowledge.

The research was initially driven by the identification of important biomedical science concepts that routinely cause difficulty among students for learning, understanding and application. These were identified by large-scale polling of experts (medical school teachers) across the United States and Canada. They were asked to propose areas of basic biomedical science that were both important to the practice of medicine and also very difficult for learners to master (Dawson-Saunders, Feltovich, Coulson, & Steward, 1990; see also Patel, Kaufman, & Magder, 1991). The resulting compilation was used to guide the research on cognitive responses to difficulty, using cognitive task analysis methods such as think-aloud problem solving. The research identified characteristics of subject matter or situations that cause difficulty for learners, including learners nearing the journeyman level of proficiency (Feltovich, Spiro, & Coulson, 1989; Feltovich, Spiro, & Coulson, 1993; Feltovich, Coulson & Spiro, 2001). The "dimensions of difficulty" that make tasks difficult and require mental effort, on the part of learners, but that are less troublesome for experts, are presented in Table 2.7.

Table 2.7. The Dimensions of Difficulty.

Static versus dynamic
Are important aspects of a situation captured by a fixed "snapshot," or are the critical characteristics captured only by the changes from frame to frame? Are phenomena static and scalar, or do they possess dynamic vector characteristics?
Discrete versus continuous
Do processes proceed in discernable steps, or are they unbreakable continua? Are attributes describable by a small number of categories (e.g., dichotomous classifications like large/small), or is it necessary to recognize and utilize entire continuous dimensions (e.g., the full dimension of size) or large numbers of categorical distinctions?
Separable versus interactive
Do processes occur independently or with only weak interaction, or is there strong interaction and interdependence?
Sequential versus simultaneous
Do processes occur one at a time, or do multiple processes occur at the same time?
Homogeneous versus heterogeneous
Are components or explanatory schemes uniform (or similar) across a system—or are they diverse?
Single versus multiple representations
Do elements in a situation afford single (or just a few) interpretations, functional uses, categorizations, and so on, or do they afford many? Are multiple representations (e.g., multiple perspectives, schemas, analogies, case precedents, etc.) required to capture and convey the meaning of a process or situation?
Mechanism versus organicism
Are effects traceable to simple and direct causal agents, or are they the product of more system-wide, organic functions? Can important and accurate understandings be gained by understanding just parts of the system, or must the entire system be understood for even the parts to be understood well?
Linear versus nonlinear
Are functional relationships linear or nonlinear (i.e., are relationships between input and output variables proportional or non-proportional)? Can a single line of explanation convey a concept or account for a phenomenon, or are multiple overlapping lines of explanation required for adequate coverage?

Table continues

Table continued

Universal versus conditional
Do guidelines and principles hold in much the same way (without the need for substantial modification) across different situations, or is there great context-sensitivity in their application?
Regular versus irregular
Is a domain characterized by a high degree of routinizabilty or prototypicality across cases, or do cases differ considerably from each other even when they are called by the same name? Are there strong elements of symmetry and repeatable patterns in concepts and phenomena, or is there a prevalence of asymmetry and absence of consistent pattern?
"Surface" versus "deep"
Are important elements for understanding and for guiding action delineated and apparent on the surface of a situation, or are they more covert, relational, abstract?

When the material to be learned or understood is characterized by the second alternative in each of the pairs in Table 2.2, then learners will tend to interpret the situations as though they were characterized by the simpler alternatives, their understandings will tend to be reductive, that is, they will tend to simplify, they will tend to attempt to defend their simple understandings when confronted with facts that suggest that the situation is more complex than what they suppose. These "knowledge shields" will allow them to maintain their incorrect beliefs and understandings. It requires effort, practice, experience (i.e., the achievement of expertise) for people to begin to overcome the knowledge shields.

This is the "reductive tendency," the inclination for learners to construct understandings and categories that are overly simplistic. The reductive tendency is an inevitable consequence of how people learn (Feldman, 2003; Feltovich, Hoffman & Woods, 2004). That is, when people are forming a new understanding or developing a new category their knowledge is necessarily incomplete. It is only through additional experience and thought that distinctions come to be perceived, understood, and learned. So at any point in time, the human's understanding of anything that is at all complex, even some of the understandings held by domain experts, is bound to be simplifying at least in some respects. In the areas of complex cognition studied (e.g., the learning of clinical medicine), the reductive tendency has been shown to lead to significant misconceptions (e.g., Coulson, Feltovich, & Spiro, 1989; Feltovich, Coulson & Spiro, 2001; Spiro, Feltovich, Coulson, & Anderson, 1989), and in some instances to degraded medical care (Coulson, Feltovich, & Spiro, 1997). In addition, the misconceptions and errors that develop can be resistant to change, an obstacle to the achievement of expertise. When learners are confronted with evidence contrary to their views, they engage mental maneuvers to rationalize their faulty beliefs without fundamentally altering their views. These are the "knowledge shields." Twenty-three of them have been identified (Feltovich et al., 2001).

Although this research first had its impact primarily in the domain of biomedical science as it relates to clinical medicine, it has found widespread application. Diverse areas where the research on the dimensions of difficulty and the reductive tendency have seen application and

validation include biology (e.g., Patel, Kaufman, & Magder, 1991), complex systems (e.g., Hmelo-Silver & Pfeffer, in press; Resnick, 1996), lay-people's understanding of disease (Furze, Roebuck, Bull, Lewin, & Thompson, 2002), work-place error and mishap (Cook & Woods, 1994), military command and control (Houghton, Leedom & Miles, 2002), and the process of design, especially the design of complex sociotechnical systems (e.g., Woods, 2002).

Studies of experts and expert-novice differences also suggested that the achievement of proficiency depends on the learner's active, deliberative creation and refinement of their own knowledge. The Cognitive Flexibility Theory of Paul Feltovich, Rand Spiro, and their colleagues (Spiro, Feltovich, Jacobson & Coulson, 1991, 1992; Spiro & Jheng, 1990) asserts that people (especially experts) have the ability to restructure their knowledge to adapt to complex, ill-structured problems. Cognitive flexibility is "the ability to represent knowledge from different conceptual and case perspectives and then, when the knowledge must later be used, the ability to construct from those different conceptual and case representations a knowledge ensemble tailored to the needs of the understanding or problem-solving situation at hand" (Spiro, et al., 1992, p. 58). This ability hinges on experience with diverse problem types, and opportunities to understand the material from differing perspectives. This enables people to refine their understanding of concepts and the relations among concepts, in processes such as those discussed by Jean Piaget (e.g., Inhelder & Piaget, 1958) and David Ausubel (1968; Ausubel, Novak, & Hanesian, 1978) such as assimilation and accommodation. The theory also asserts that knowledge and knowledge-in-use are context-dependent, and so instruction needs to be with reference to meaningful contexts. This entails some straight-forward guidelines for effective instruction:

- Learning activities must provide multiple representations of content.
- Instructional materials should avoid oversimplifying the content domain and support context dependent knowledge.
- Instruction should be case-based and emphasize knowledge construction, not transmission of information.
- Knowledge sources should be highly interconnected rather than compartmentalized.

These guidelines have been widely and successfully applied (e.g., Jonassen, Ambruso, & Olesen, 1992).

2.3 Training and Practice

Most traditional training covers what is generally familiar and well-known to trainers, educators and training establishments in the context of bounded operational and organizational settings. As such the 'training for the test' measures can be base-lined and validated to create normative performance scores. It is still appropriate for training in many jobs/tasks to rely on checklist evaluation based on correct or expected answers or fixed procedures.

However, the need for or a capacity for critical thinking (in terms of thinking laterally and innovatively or being able to improvise) and capability to engage with what cannot be or has not been foreseen is central to many existing and emerging jobs/tasks, including many emerging

military jobs (e.g., cultural analysis, SASO operations, PIMESII, etc.) (Center for Applied Systems Studies, 2010).

If there can be any one generalization about the science of training and instructional design it is:

Generalization is difficult.

2.3.1 Types of Practice and Training Sequences

Massed versus Distributed Practice

A long line of psychological research has shown the beneficial effect of spacing on learning and memory when the goal is long retention intervals (e.g., Bahrick, Bahrick, Bahrick, & Bahrick, 1993; Bjork & Allen, 1970; Bloom & Schuell, 1981; Dempster, 1988; Glenberg, 1976; Glenberg & Lehmann, 1980; Greene, 1989; Reynolds & Glaser, 1964; Schmidt & Bjork, 1992).

Some studies find that optimal performance at test seems to result when the interval between practice trials is approximately equal in length to the retention interval. This conclusion seems to hold even when practice is distributed across sessions rather than across trials within a session (Healy, 2007.)

With respect to military tasks looking at massed versus distributed practice, similar evidence has been found. For example, Hagman (1980) varied this type of practice in a maintenance task and found that, when tested two weeks later the participants in the massed practice condition committed 40% more errors and took 51% longer than the distributed practice group.

This finding has a direct implication for retraining following hiatus. Many ideas about skill retention during hiatus involve practice experiences that would inevitably be massed in the sense of concentrated at particular times within the practitioner's primary work schedule. The literature on distributed practice would suggest that training during hiatus be distributed.

Blocked versus Scheduled Practice

Blocked practice refers to practice in which there are successive trials that repeat a particular activity. This is contrasted with a randomized schedule in which the same task is never practiced on successive trials, but is randomized with other practices. A number of researchers have found that retention is better in random versus blocked practice schedules (Landauer & Bjork, 1978; Rea & Modigliani, 1985). This holds true for both simple motor skills and simple verbal memory tasks. It is theorized that randomized practice forces the learner to continuously engage with new and difficult information to process, which can be to the detriment of initial retention, but prevents reliance on a stable set of "superficial massed rehearsal." This allows for greater long-term retention.

Sequencing by Content Type

There is considerable evidence that training experiences need to be sequenced with respect to the "knowledge type." Koubek and Clarkston (2004) demonstrated that training can affect the development of knowledge structures which can in turn affect training effectiveness. Their study focused on the question of whether trainees benefit more from first learning about domain concepts and principles, or first learning about specific details of tasks, and procedures. Students with no prior knowledge about plastic extrusion machines were taught about plastic extrusion by

presentations in one of two orders involving the two training topics of domains concepts and principles, or by versus details of processes. Trainee knowledge was assessed by asking for trainees to indicate the relations between all possible pairs of domain concepts (e.g., mold-warpage, resting period-barrel). These pair-wise judgments could be used to form hierarchical models of the trainees' "knowledge structures," which could be evaluated for correctness, completeness, and complexity (number of hierarchical levels). Overall, the group receiving the first training about concepts and principles did better on the final test (i.e., more levels in the knowledge hierarchies and more interconnections among concepts).

One must note that the participants were naive to the domain at the outset, and also received no actual experience with plastic extrusion machines. Likely the ordering of the conditions, and the resultant effects, would differ were one to have apprentices or journeymen with actual experience as the participants.

Sequencing by Complexity

It is sometimes assumed that the way to help learners cope with complexity is to simplify the situation and then incrementally introduce increasingly complex elements. However, initial learning that is more difficult can lead to greater flexibility and transfer. Research on high-end learning (e.g., in medical education) has shown that when learners are initially exposed to simplifications of complex topics, serious misunderstandings can remain entrenched and interfere with or preclude deeper, more accurate understandings (Feltovich, Spiro, & Coulson, 1993). Complex tasks are typically taught as a procedure when it is more appropriate to train it as:

> "…a combination of domain and system knowledge (conceptual models of the system including system components and interaction, flow controls, fault states, fault characteristics, symptoms, contextual information and probabilities of occurrence); troubleshooting strategies such as search and replace, serial elimination, and space splitting; and fault testing procedures" (Jonassen, 2007, p. 12).

Sequencing by Readiness Level

A well-known finding in research on text comprehension is that low-knowledge and high-knowledge readers learn different things and in different ways (e.g., MacNamara, et al., 1996).

Based on a review of research on student learning from textbooks and diagrams, Mayer (2001) concluded that inexperienced learners benefit far more from instructional presentations designed to provide a better support for cognitive processes than high-knowledge learners. Less knowledgeable learners benefit from additional, integrative material whereas more knowledgeable learners do not.

Kalyuga, et al. (2003) reviewed the literature showing that learning depends on the level of proficiency (expertise) of the learner. Instructional techniques that are highly effective with inexperienced learners can lose their effectiveness and even have negative consequences when used with more experienced learners. Conversely, instructional methods that work for more advanced learners may be ineffective for less advanced learners. One hypothesis has been that "schemas" stored in long-term memory (said to be a defining feature of expert memory organization) reduce working memory load during learning and thereby aid learning. For less

advanced learners, instructional guidance can compensate for the learner's lack of schemas.

> If the instructional presentation fails to provide necessary guidance, learners will have to resort to problem-solving search strategies that are cognitively inefficient because they impose a heavy working memory load (p. 24).

In contrast, since more advanced learners bring their memory schemas to bear, if the problem task includes integrative material, this can be a distraction.

> This additional cognitive load may be imposed even if a learner recognizes the instructional materials to be redundant and so decides to ignore that information as best he or she can (p. 24).

For the novice learner, excessive working memory load inhibits the ability to adequately process material if it is beyond their level of expertise. For experts, on the other hand, learning is inhibited if they are forced to work with material below their level of expertise, because it forces redundant processing. This is referred to, somewhat misleadingly, as the *expertise reversal effect*: experts are more likely learn if they are given the opportunity to engage in exploratory problem solving that engages previously acquired schemas, whereas novices are likely to benefit from worked examples that do not involve exploratory problem solving. This accords with the guidelines of Problem-Based Learning.

In a study of comprehension of electrical circuit diagrams, Kalyuga, Chandler, and Sweller (1998) found that less experienced electrical trainees benefitted from textual explanations accompanying the circuit diagrams that were not able to comprehend in a diagram-only format. More experienced trainees performed significantly better with the electrical circuit diagram-only format and reported less mental effort associated with studying the diagram-only format.

A host of studies have shown that when learning to solve problems of a given kind, examples help. Beyond this finding, presenting example problems that are fully worked-out can sometimes be as good an instructional method as presenting incomplete problems that the learner has to work out (e.g., Trafton & Reiser, 1993). However, this too can depend on the learner's proficiency level. Once a student has learned to solve a problem type to a reasonable level of proficiency, when problem solving becomes less effortful, presenting a fully worked example that the student has to work through can entail a cognitive load greater than that of problem solving (Kalyuga, et al., 2001).

> ... inexperienced learners benefitted most from an instructional procedure that placed a heavy emphasis on guidance. Any additional instructional guidance (e.g., indicating a goal or subgoals associated with a task, suggesting a strategy to use, providing solution examples, etc.) should reduce cognitive load for inexperienced learners, especially in the case of structurally complex instructional materials. At the same time, additional instructional guidance might be redundant for more experienced

> learners and require additional working memory resources to integrate the instructional guidance with learners' available schemas that provide essentially the same guidance. A minimal guidance format might be more beneficial for these learners because they are able to use their schema-based knowledge as guidance in constructing integrated mental representations without overloading working memory (Kalyuga, et al., 2003, p. 27).

Such an interaction also obtains for the effect of mental practice, which is more beneficial for more advanced learners than less advanced learners. This is also explained on the hypothesis that advanced learners have developed mental schemas (Cooper, et al., 2001).

The findings and effects described here depend on the nature of the to-be-learned material. Some material consists of elements or chunks that can be understood separately, whereas other material consists of elements or chunks that have to be understood as an interacting whole. If a learner understands material in an integrated way, they will have formed schemas that can be used to organize information presented in new problems. Novices need to be presented the information in such a way that they can understand the individual elements and then develop the integrated understanding, but such "mixed instruction" does not benefit more advanced learners (Pollock, et al., 2002).

Learning Styles

Although school children up through adults will indicate that they prefer to learn in certain ways and from certain kinds of instructional formats (so-called learning styles), and there is ample evidence that people differ in aptitude for learning different kinds of material and reasoning in different ways, there is no evidence for the interaction between these two that a learning styles hypothesis would predict. That is, there is no clear evidence that students having one particular learning style will achieve the best educational outcome when trained using a method that matches their style, as opposed to training that matches some other learning style (Pasher, et al., 2009).

Types of Training and Practice: Mental Practice

Given that mental rehearsal or imaginary practice appears to be an effective strategy to reduce forgetting or skill decay during the retention interval, mental rehearsal can be considered "practice." Research has shown that mental practice can serve as an effective substitute for physical practice for both enhancing knowledge of particular sequences and improving general skill. Indeed mental practice might be superior to physical practice under circumstances that promote retroactive interference. By hypothesis, mental practice can retard forgetting and promote transfer of training (Healy, 2007).

Measurement Issues

Sequencing, whether by content or by readiness, has implications for evaluation. Dodd (2009) presents a useful scheme for classifying military jobs in terms of kinds of knowledge required and types of decision-action roles. For example, the equipment operator needs technical skills to operate equipment and conceptual knowledge to diagnose and repair problems. The unit

commander, in contrast, requires conjectural skill and problem solving skill to cope with complex situations.

Such cognitively different jobs require different forms of learning and experience, which in turn will be best measured in ways that are appropriate to the cognitive work. For example, time taken to complete tasks and degree of confidence are useful training measures for certain jobs and tasks. However, they may not tap into the decision-maker's approach to situation assessment, or ability to spot anomalies, or motivation to practice in at unfamiliar and unforeseen situations.

2.3.2 Problem-Based Learning and Guidance Fading

The educational philosophy of John Dewey (1916) advocated "learning by doing" and emphasized the development of critical thinking skills through problem solving exercises. Originating primarily in the area of medical education, Problem-Based Learning is an instructional method that has students collaborate in work on challenging practical problems (ill-structured, open-ended, ill-defined). Instructional activities include case-based or analogical reasoning, causal reasoning, story creating, concept mapping creating stories; reasoning about cases; concept mapping, and others (see Hmelo-Silver, 2004; Hmelo-Silver, & Barrows, 2006).

Research by Sweller (2006) and his colleagues on how students learn algebra suggests that Problem-Based Learning is more effective for later or more advanced learning rather than initial learning. Indeed, they find that initial learning is facilitated if the trainee studies "worked examples" (Sweller & Cooper, 1985; Cooper & Sweller, 1987). Early in the learning process, learners may find it difficult to process a large amount of information or assimilate concepts at odds with their existing knowledge. Thus the rigors of active problem solving may be an issue for initiates. Once learners gain expertise the scaffolding provided by in Problem-Based Learning helps learners avoid these issues. Sweller calls this "guidance fading." Worked problems are replaced by completions problems, with the eventual goal of solving problems on their own (Sweller, Van Merrienboer, & Paas, 1998).

The fading notion is defined with reference to a concept of "cognitive load" and the goal of reducing the cognitive load of learners. This does not directly accord with the theory of "desirable difficulties," which asserts that any condition that causes a desirable difficulty during learning facilitates retention (Bjork, 1994; McDaniel & Einstein, 2005; Schneider, et al., 2002). Research has established the finding that learning at initial and intermediate levels can be faster under easy conditions than under difficult conditions; performance immediately after learning will tend to be better for students who learned under easy conditions than under difficult conditions. However, when testing is after a delay or in a slightly changed situation, it is often found that performance is better for trainees who learned under difficult than under easy conditions. In fact, introducing desirable sources of difficulty or interference during training has been shown to be an effective way to promote retention and transfer (Healy, 2007).

The fading notion also does not accord with what is known about expertise: The achievement of high proficiency entails increasing the task difficulty, not decreasing it. Thus, a simple fading hypothesis is bound to be incomplete.

What might be generalized is a notion of guidance *changing*, not guidance fading: What "counts" for difficulty, and a desirable difficulty, differs from early versus more advanced learners. Sometimes withholding information or assistance can lead to defeat and sometimes it involves a desirable difficulty that helps the learner advance to higher levels of capacity. The

"Assistance Dilemma" is for the researcher or instructional designer to determine what is optimal for a given learning domain (Koedinger, et al., 2008).

> Long-standing notions like zone of proximal development (Vygotsky, 1978)... or model-scaffold-fade (Collins, Brown, & Newman, 1990) suggest that instructional assistance should be greater for beginning learners and be reduced as student competence increases. Such long-standing notions and the more recent extensive experimental research on cognitive load, desirable difficulties, etc. might lead one to wonder "what's the dilemma?" Just give novices more assistance and fade it away as they become more expert. However, current theory does not predict how much assistance to initially provide nor when and how fast to fade it (Koedinger, et al., 2008, p. 2156).

2.3.3 Feedback

Research shows that giving and withholding of assistance or feedback have both costs and benefits. Sometimes instructional assistance can be a crutch that does not substantively advance the learner's capabilities, sometimes it can be a scaffold that does. At the most general level, training should balance giving and withholding information or assistance to achieve optimal student learning. Key research results and generalizations concerning feedback have been presented in many reports and reviews (e.g., (e.g., Marton & Säljö, 1976). Some were mentioned above in the discussion of Desirable Difficulties.

In the literature on the learning of simple tasks, it was sometimes assumed that feedback is best when provided close in time to performance, but this is not necessarily the case at all. While immediate feedback may improve performance in the near-term, it can also have the opposite effect on long-term performance. When learning a skill that is knowledge or reasoning-intensive, the learner benefits from having the time to think back on poor performance and cogitate on what was done right, what was done wrong, and what might be done differently in the future. Immediate outcome feedback can prevent such post-task cogitation and thus not contribute to accelerated proficiency or the improvement of metacognitive skills (thinking about one's own reasoning strategies).

While feedback is able to guide the learner toward the correct behavior, it can also inhibit performance in the long run in other ways (Schmidt, 1991). If feedback is too frequent, it blocks important information processing activities. Furthermore, if there is too much feedback, it becomes part of the task itself, and no longer serves the function of reflection and organization of information.

It should be noted in this context that the importance of feedback links in a significant way to what is known about high proficiency (i.e., expertise.) Over the past two decades, the field of Expertise Studies has revealed a significant difference between two kinds of domains. In Type 1 domains it is relatively easy to define expertise and find true experts. Examples are sports, medicine, and weather forecasting. In Type 2 domains, it is not easy to define expert performance. Examples are jurisprudence, economics, and psychotherapy. Type 2 domains are ones in which the principal task goals involve predicting individual or aggregate human behavior

(Shanteau, 1992), but they are also domains in which feedback is minimal to non-existent, or is often significantly delayed. Domain-dependence is a very important consideration for any training program aimed at accelerating the achievement of proficiency.

Types of Feedback

Most learning researchers and theorists have discussed the importance of feedback and many have highlighted the significant difference between outcome feedback and process feedback. The latter informs the learning of such performance aspects as correctness or accuracy and the latter provides information and the learner's process and what might have been good or not good about it. Both forms of feedback can be valuable to learners. For example, error analysis and correction, as a form of feedback training, is exemplified by After Action Reviews (Hunt, 2009). It is critical to recognize that feedback can be, and typically has to be, a mixture of types and delivery strategies: immediate vs. delayed, outcome vs. process.

Corrective Feedback

Studies of diverse domains of expertise reveal a great variability between domains (and specializations within domains) in the extent to which workers receive any feedback, let alone timely, high-quality feedback (e.g., Salas, Nichols, & Driskell, 2007). In some cases, the inherent nature of the domain makes it impossible for the practitioner to receive timely feedback (e.g., long-term weather forecasting, intelligence analysis for policy projection). This may be one reason why it can take a decade or more for an individual to achieve expertise.

Experts learn more from their mistakes than from what they get right. It has been said that apprentices make the same mistake twice, journeyman make the same mistake once and experts work until they never make mistakes. While this is a point well taken, domain specialists who are intrinsically motivated often *seek out* corrective feedback that allows them to perceive their errors (Sonnentag, 2000). The more highly experienced and motivated domain practitioners seek feedback from coworkers. When everything works the way it is supposed to, one is less likely to receive feedback about what did not work or what might have been done better. As such, experts seek out *corrective feedback*, feedback pointing out targets for improvement. Cognitive Flexibility/Transformation Theory suggests that feedback should help the learner transcend the inclination to invoke a knowledge shield (i.e., rationalize away a misunderstanding), and un-learn concepts or notions that incorrectly simplify their understanding of the domain.

Continuous Feedback

It is possible for feedback to be continuous. That is, the learning environment provides continual displays of performance indicators. This is called "dynamic assessment." Continuous feedback and monitoring as learners encounter increasingly complex problems, can accelerated the achievement of proficiency in certain tasks (Pellegrino et al., 2001; Frederiksen, 1990; Lajoie & Lesgold, 1992). Feedback also allows for more active self-monitoring and self-assessment, which can enhance the development of proficiency (Lajoie, 2003; Bransford & Schwartz, 1999; White, Shimoda, & Frederiksen, 2000).

Educational psychologist John Bransford (2009) introduced the notion of "transfer-appropriate processing" in cognitive science (Barclay, et al., 1974; Bransford & Franks, 1976; Bransford et al., 1979). In his recent studies of classroom learning he has focused on expertise at teaching at primary and secondary school levels. Bransford and Schwartz (2009) speculate that the best conditions for the development of expertise are those that afford bi-directional feedback between

teachers and learners—where the teacher learns from the students and the students learn from the teachers. They advocate the use of simulations, to reinforce they ability to apply knowledge. They refer to "Top Gun" kinds of training programs as ones that seem to provide such bidirectional feedback and are successful—representative, measurable tasks with record of performance and guided feedback. Lack of feedback is argued the reason that many professionals in some domains (e.g., clinical psychologists) seem not to improve. Bransford and Schwartz also address the problem of "inert knowledge," learners not being able to apply what they have "learned." He sites some forms of learning that are addressed to this problem, for example Problem-Based Learning.

Debriefing as a Form of Feedback

The comparison of training in the military with issues in sports is interesting for two reasons. One is the overall similarity of training approaches and the second is the possibility of adapting training methods used on athletics over into military arenas (Fiore, Hoffman & Salas, 2008).

In competitive sports it is standard practice for athletes to closely monitor and tabulate performance and to engage in preparatory behaviors in service of improvement and reflective behaviors in service of diagnosing good and poor performance. One practice method that is associated with this in sports is the technique of studying "game tapes." Teams spends hours analyzing their opponent (i.e., the team for which they are preparing) as well as hours discussing and reviewing tapes of their actual play against that team. This, of course, bears similarity to the military's use of the brief-debrief cycle in which teams engage in reflexive activity and systematic integration of preparation, execution, and reflection (see Fiore, Johnston, & Van Duyne, 2004; Vashdi, Bamberger, Erez, &Weiss-Meilik, 2007).

Preparation involves pre-task activities such as planning through the use of techniques such as briefing visualizations or the use of technologies such as mobile learning devices (see Metcalf, 2006), where initial expectations are created in anticipation of the interaction. Reflection includes post-task rumination on performance (e.g., debriefing), where task feedback can be administered to individuals and/or groups via after-action review technologies (see Fiore, Johnston, & McDaniel, 2005).

All branches of the military, and organizations within the branches, have detailed protocols for mission debriefing intended to result in "lessons learned" (and not just conduct root cause analysis of critical incidents) (e.g., Hernandez, 2000). In U.S. Air Force training using debriefings there is a set structure to debriefs (Brown, 2006). An example is the five phases of an F-16 debriefing for a "flight lead": (1) gathering data, (2) an "administrative phase" in which the flight lead covers issues not main to the mission, (3) reconstruction of the mission, (4) analysis of "why questions," and (5) generation of lessons learned. The main motivation appears to be increased efficiency and accuracy in the conduct of debriefing amidst the fog of war and making the debriefing fast and accurate (Hernandez, 2000). It is not clear how this might contribute to making debriefing a learning experience, or might detract from it.

Brown (2006) has presented recommendations that would likely make debriefs more of a learning experience. This paper proposes a detailed, standardized procedure for conducting debriefings, focusing on Debrief Focal Points (DFP). It is prompted by the perception that current debriefs can be improved. In that regard, the author notes common shortfalls including: The Debrief Focus Points method is intended to prevent inaccuracies in mission reconstruction,

and focus on the determination of "contributing factors" and root causes, and use those—in the debriefing itself—to generate instructional fixes.

Debriefing can rely on Instrumented Debriefing Systems (IDSs), which use mocks of aircraft instrumentation to aid the pilot in the debriefing process. This idea emerged in the 1970s and has been used for debriefs of large-scale exercises as well as debriefs for individual pilot mission debriefs. Despite the growing fidelity and availability of IDSs, most syllabi across the combat air forces require students to reconstruct missions by drawing. Greater reliance on IDS is recommended (Gaetke, 2009), to facilitate mission reconstruction rather than forcing the pilot to get "lost in the weeds" trying to correctly draw mission sub events (e.g., a turn radius based on the fact the fighter was 16° nose low?) and also to make the debriefing more of a learning/training experience.

In conclusion, there is variety to debriefing methods and debriefing goals, and not all of these can or should be changed or standardized since they are formed, in part, by the urgencies and exigencies of combat situations. That being said, there are suggestions for changes in debriefing procedures that might make debriefings more of a learning/training experience. Generally, these involve structured methods for scaffolding the process of retrospection and reconstruction.

2.3.4 Desirable Difficulties

Psychologist Robert Bjork (1994, 1999, 2001, 2009: Bjork & Allen, 1970) has emphasized a number of useful generalizations from academic research:

- What counts as an appropriate instructional method depends on whether the learning is initial learning or is advanced and longer-term.
- Learning benefits from errors with good feedback.
- Cases or problems that make initial learning difficult (e.g., learning a sequence in mixed parts, rather than just sequentially), can aid long-term learning and higher order learning, such as transfer. Bjork calls these "desirable difficulties."

Examples include:

The finding that methods that lead to good immediate reproductive memory (such as massed practice) may not be well suited to longer-term retention, or transfer.

The finding that making task performance harder during instruction by delaying feedback can lead to better long-term retention (see Schmidt and Bjork, 1992).

The finding that worked examples make performance easier during initial instruction, and greater variability in example content makes performance harder during early instruction. But variability-based early instruction also contributes to better learning later on (Paas & Van Merrienboer 1994).

The notion of "desirable difficulty" resonates with the method called Problem-based Learning (see Boshuizen, 2009).

The ideas about "desirable difficulties" resonate with what is known about high proficiency, in particular the implications for training and mentoring that derive from the Cognitive Flexibility/Transformation Theory (see Section 4.3.1).

While the concept of desirable difficulties has surface validity, and is a concept upon which this Report relies, it is not clear how to operationalize the definition of desirable difficulty and distinguish desirable from undesirable difficulty. It is a certainty that what constitutes a desirable difficulty is dependent on context and upon the trainee's level of proficiency. "Training for complex tasks is itself a complex task, and most principles for good instruction are contextual, not universal" (Reigeluth, personal communication).

2.3.5 Mentoring

The English word "learn" comes from words meaning to *lead*, in the literal sense of a track or rut caused by a wheel. This explains the origins of idioms such as to get off track, or in the extreme, as in delerium (de <down> -laeria <track>). From its origins describing wheel tracks, *laern* evolved in Romance languages to denote the process in which one person leads another: the teacher and student relationship. In Old High German OLD High German, learn meant not the process in which one person remembers information. Rather, it is a two-person relation meaning to cause understanding.

In any given operational work environment, whether in the private sector or the military, there will be individuals who span the proficiency continuum, including trainees (apprentices), journeymen, and experts. Workers at all levels are generally accountable for one another's actions. Often this takes the form of mentoring, which can be done informally or out of intrinsic motivation, or can be a formal organizational process and requirement (see Hoffman, et al., 2002). Workers devise coordinated solutions that mix expert and trainee contributions (Lajoie, 2003).

It is widely recognized that mentoring is important in organizational learning (e.g., Ford, 2000). Workforce trends are raising the stakes with regard to on-the-job training and mentoring. Increasing complexity, pace of change, pace of decision making, and increasing worker mobility, all entail fewer opportunities for mentoring (Becerra-Fernandez, Gonzalez, & Sabherwal, 2004). Because of these trends, national policy is being formulated to support research and development in an educational infrastructure capable of producing the next generation of the science and technology workforce (see Committee on Science, Engineering, and Public Policy, 2006). Even if such initiatives are successful, the results will be far too distant to help solve the immediate utilities workforce issues.

In some of the craft guilds of the middle ages, a "master" was any practitioner who was qualified to teach, in recognition of the special qualities that a good mentor must possess (Hoffman, 1998; Renard, 1968). Thus, even a journeyman could be qualified as a master. The field of Naturalistic Decision Making has approached the nature of a good mentor. In *Sources of Power*, Klein (2003) described the kinds of techniques that skilled mentors use and the kinds of skills mentors need to develop for diagnosis, presentation of material, and setting the right climate for learning. There is some research on what makes for a good mentor in the sense of coaching in sports (Fiore & Salas, 2008) and there is a large literature of what makes for a good teacher (see Mistrell, 1999; Proctor & Vu, 2006). But little is known about what makes for a good mentor in the context of the modern sociotechnical workplace. Little is known about how to mentor individuals in the progression from journeyman to expert.

Klein (2002, 2003) has observed mentoring activities in the job context. The mentor establishes a relationship and environment that fosters learning, diagnoses the reasons why the trainee is struggling, and tailors instruction to fit the situation. The best mentors accomplish all three. They have a repertoire of strategies for getting material across (e.g., demonstrating the task while thinking out loud, interrogating the trainee for the rationale behind actions, asking the trainee to instruct them, etc.). Less effective mentors or coaches usually have a very small repertoire, often just a single or "rote learning" mode of lecturing to the trainee about the procedures to be followed.

Hoffman (1998) described the key characteristic of the expert mentor:

- The ability to form rich mental models of the learner's knowledge and skill.
- The mentor can anticipate when the learner will form a reductive mental model,
- The mentor can anticipate the kinds of cases that will lead the learner to form a reductive model, the mentor can recognize the kinds of practice experiences that will force the learner to go beyond his current reductive models.

Studies of the development of high levels of proficiency and studies of training have both shown that mentoring or "dynamic assessment" has to include opportunities to receive rich process and outcome feedback as learners encounter increasingly complex problems (Glaser & Bassock, 1989; Frederiksen, 1990; Lajoie & Lesgold, 1992; Pellegrino et al., 2001). Enabling learners to visualize the trajectory of change through models and feedback also allows for more active self-monitoring and self-assessment, which can enhance expertise development (Lajoie, 2003; Bransford & Schwartz, 1999; White, Shimoda, & Frederiksen, 2000).

Mentoring has not been demonstrated or studied at the higher levels of proficiency and extraordinary expertise (e.g., prodigies, musicians, etc.). There is some research on what makes for a good mentor for coaching in sports (Fiore & Salas, 2008), and there is a large literature of what makes for a good teacher (see Mistrell, 1999; Proctor & Vu, 2006). But little is known about how to find good mentors, or what makes for a good mentor in the context of the modern sociotechnical workplace, and little is known specifically about mentoring individuals from journeyman level to expert. There is an outstanding practical need for methods for rapidly identifying individuals having the most experience in the role of mentor, and then cognitive task analysis to reveal the reasoning strategies of mentors, especially as they deal with mentoring situations that are challenging. The motivation of experienced workers to pass along their "tough case" knowledge is frequently there, but due to the bureaucratic habit of expecting that mentoring will succeed, they are often left not knowing how to proceed, or even knowing that their tough case knowledge is critical and highly informative to apprentices.

Mentoring as a means to share knowledge within organizations has been receiving more attention in recent years in the literature on knowledge management and organizational learning (Zachary, 2007). Recommendations include the need for leaders to cultivate a "mentoring culture," engage workers at all levels in the design and implementation of mentoring programs, create value and incentives for mentoring, and, importantly, focus mentoring in insuring a succession of key expertise (as opposed to the loss of capability). Organization leaders should include mentoring capacity as a part of the performance development plan for new leaders. Leaders themselves should serve as role models for mentoring, Of particular benefit for leaders is that mentoring programs help keep them abreast of developments in their workers' fields of practice: mentoring morphs as new knowledge comes into the business environment.

2.3.6 Scenario-Based Training

Scenario-based training is an idea related to that of Problem-Based Learning, but is a generalized form, expressing the value of training by use of specific problems, cases, stories, or scenarios (Fletcher, 2009).

Military and civilian jobs are gaining in complexity and unpredictability such that conventional (e.g., classroom) methods of training have become ineffective and there is a need to train for adaptability and flexibility (Shadrick & Lussier, 2009). There can be little doubt of a consensus in the research community that training for adaptability and flexibility has to rely on case-based methods of training in which important themes are explored in representative complex situations, with feedback.

Ways of Using Scenarios

It is important to distinguish Distributed Learning from Computer-Based Training. Literally, both are media through which instruction can occur. CBT is, we might say, a more traditional form of instruction, in which the program controls the flow of instructional activities. In Distributed Learning permits practice "anytime anywhere," but it also is generally formed around case experiences or scenarios. The learning experience is more situation-oriented and the learner controls the flow of events and experience. Thus, Distributed Learning is regarded as more appropriate for high-end learning because it makes the student responsible ("active learning, or "action-initiation") and has potential to be more motivationally engaging. In addition, it is the one new instructional technology that is being to bear on the notion that it can help organizations, including the military, adapt to increases in the complexity and technology of work (Kozlowski & DeShon, 2005).

Computer-based simulations are increasingly being used to teach abstract or conceptual information (Miller, Lehman, & Koedinger, 1999; Resnick, 1994; Schank & Farrel, 1988). By providing perceptual grounding for abstract concepts they aid in comprehension, and the interactivity can support a deeper understanding of the material (Goldstone & Sakamoto, 2003).

2.3.7 Virtual Reality-Based Training

It has been demonstrated that a virtual reality experience can supplement the acquisition of declarative knowledge. For example, Greenstein, et al. (2008) investigated the effect of "Second Life" experiences in the learning of introductory material in the physical and behavioral sciences. In learning about tsunamis and about schizophrenia, students who completed both a Second Life experience and read a handout achieved higher test scores and rated the learning experience more engaging than when they completed the handout alone. The Electric Power Research Institute (EPRI) several years ago identified VR technology as possibly being useful, and launched a number of projects (Naser & Hanes, 2008). For purposes of the present Report, the most interesting of these was the creation of a virtual model of an air-operated valve to support maintenance and training. For training, videos were created showing animated disassembly and assembly procedures. Also, step-by-step disassembly and assembly sequences were provided requiring the user to select the correct next step.

The VR system also played into the process of capturing and sharing the knowledge of the most proficient workers. The virtual valve model was used for eliciting valuable tacit (undocumented) knowledge from experts as they went through the valve maintenance procedure. This knowledge was hyperlinked to valve parts, and could be accessed by clicking on the displayed link. The virtual valve and associated knowledge could be made available to workers who could benefit from its availability. In what follows, we refer to this as a "Virtual Reality-plus-Knowledge" model, or VR+K model.

Another project developed a VR+K model of a pressurizer room facility. Virtual models were created from point clouds produced from laser scans of the room. One model showed the room as scanned but with colors added to surfaces representing the different radiation levels in the room. The models were used to elicit valuable knowledge from experts as they went through scenarios for preparing the room for a re-weld effort. This knowledge was linked to appropriate locations on the virtual models, and could be accessed by clicking on the displayed hyperlink. The models were shown prior to room entry to workers preparing the room for the re-weld effort, and to outage contractors who performed the re-welding work. EPRI saw two highly significant benefits. Time for rework due to worker errors would be reduced because of more effective training and availability of expert knowledge, and workers received significantly lower radiation doses because efficient maintenance entailed reduced exposure time and because they had a knowledge of the "hot" area locations as shown in the virtual model with colorized radiation levels.

> It was estimated that a worker trained with a virtual valve would require about five to ten percent less time to perform the actual maintenance. This is attributable to the worker developing a better mental representation of the valve design and required actions. Thus, he is able to concentrate on the work to be accomplished rather than where parts are located and how to disassemble and reassemble them correctly (p.2).

Table 2.8 Demonstrated benefits of virtual reality-based training.

DEVELOPMENT BENEFITS	TRAINING AND PERFORMANCE BENEFITS
Virtual models can be created quickly, easily, and at low cost from 3-D CAD files.	Virtual models and associated expert knowledge can support job planning and training.
In some contexts, models may be viewed in 2.5-D on existing PCs and on 3-D VR systems, although 3-D representations may not be necessary.	The virtual models were found to be an excellent tool for pre-job briefings; the actual work area could be viewed in detail rather than the abstract "bird's eye" view provided by architectural drawings.
Model portability supports its use for just-in-time training wherever a worker is located as contrasted with the need for the worker and mock-up to be physically together.	Worker briefing time was found to be about the same, but the virtual models provided workers with more confidence of what they would encounter.
These demonstrations involved tool evaluation by over 100 utilities workers. The findings support the notion that a merger of VR training with expert knowledge elicitation might be foundational to acceleration methods.	Workers asked more questions in briefings in which the models were used, and contract workers commented they had a better understanding of what they would encounter in the room as compared with briefings at other plants.
A virtual model and associated resources, once created, can be used repeatedly and the knowledge base expanded in the future.	To the experts from whom the knowledge was captured, the process of knowledge elicitation made them able to recognize when to provide knowledge during the briefings.

The main limitation that EPRI pointed to was that while virtual models are useful for training, they can be of limited value for planning tasks that are highly routinized or proceduralized. This is, perhaps, to be expected. Indeed, a long-term view of the VR approach relates directly to the role of training and proficiency to cope with unique events:

> It is becoming difficult for the utilities to obtain needed contract workers to support recovery from outages. It is likely that contractors and plant new hires in the future will be younger and less experienced. Virtual models and associated expert knowledge could be important tools to provide these people with needed training (p. 3).

A VR+K model of a facility would make is possible for workers to familiarize themselves in advance with equipment locations, work locations, and routes to and from work locations.

2.3.8 Training for Flight Situation Awareness

One of the significant skills in many domains is the "education of attention." Especially in tasks or situations where decisions are high-stakes and must be made under time pressure, it is important for the decision maker to be able to manage their attention and deliberately attend to the significant features or events in the environment. The concept of attention retains its

centrality today in communities of practice where it has come to be known as "situation awareness" (SA) (Endsley, 1992).

Attention has been a central concept in psychology since psychology emerged as a branch of philosophy in the 1800s. Attention is a bridge between sensation and memory—what one is sensing is linked somehow to the concepts and categories residing in memory, allowing for recognitio=on and then fuller understanding. This is essentially what the theory of SA is all about. Situational awareness is seen as a bridge between information and dynamic mental models of the current situation (paralleling the historically prior doctrine concerning the relation of sensation and memory).

SA has been a topic for considerable research in human factors and cognitive engineering (see, for instance, Sohn and Doane, 2004; who attempted to predict piloting SA by measures of working memory capacity). SA is now used broadly to refer collectively to a number of phenomena of cognitive work: mental model formation, sensemaking, projection to the future, and others (see Klein & Hoffman, 2008). Thus it is applied in many work and domain contexts and is measured in a variety of ways (see Endsley & Garland, 2000). An analysis of SA based on the judgments of fighter pilots listed 31 component elements, ranging from tactical knowledge to planning ability (Waag & Houck 1994)

The origins of the SA term and concept are in military aviation, specifically, the ability of the pilot in a dog fight to "get inside the OODA loop of his opponent." (In a sense, training for flight SA is what Top Gun is all about; see Carroll, 1991) Traditionally, pilot skill at "getting inside the opponent's head" and anticipating the opponent's actions have been assessed by peers and experienced pilot trainers using rating scales based on SA elements. It is still so evaluated, and is known to be highly reliable and correlates with SA as measured in simulated combat missions (see Bell & Lyon, 2000).

The measurement of SA is in some applications somewhat equivalent to measuring performance, and the "getting inside the opponent's head" feature of SA is a defining feature that has been lost in most of the applications of SA, which now seems to refer to general attention to cues and patterns and dynamics of unfolding events in the world, not to the attempt to reason about someone else's reasoning. "SA is an abstraction that exists within our minds, describing phenomena that we observe in humans performing work in a rich and usually dynamic environment" (Billings, 1995).

The "Levels of SA" are a clustering of mental processes, most of which were substantively described in the 1700s and 1800s. SA Level 1 as described involves mental operations including sensation, cue detection, feature identification, monitoring, awareness of states, perception, attention, and others. SA Level 2 involves perception, comprehension, and interpretation ("of that portion of the world that is of concern to the observer"). Level 3 SA is called "projection." Psychologists of the early eras referred to this as "imagination" and "apprehension." Since the 1980s, it has been known in cognitive psychology as "mental model formation." Level 3 SA is conscious awareness of the ongoing events in the world in terms of the observer's knowledge (i.e., knowledge of the status and dynamics of the elements and comprehension of the situation). Level 1 and Level 2 awareness is "extrapolated forward in time to determine how it will affect future states of the operational environment."

The notion of level does imply that events or outcomes at one level feed into events at the next higher level. But given the slipperiness of the categories of these mental operations, mental

functions can be seen to inhabit more than one Level. Levels 2 and Level 3 both involve forms of judgment or evaluation. All of the SA processes depend on memory and contact with knowledge. They all involve some form of understanding, or "developing a comprehensive picture of the world." Level 2 SA is said to involve the integration of information, but that includes integrating information to understand how it *will* impact upon the individual's goals and objectives. The use of future tense would seem to ascribe the mental process to Level 3.

It is sometimes apparent when awareness has gone from sensory detection of some sort of occurrence (What was that?), to an interpretation of that occurrence (It's a dog), and thence to a broader understanding of an event (I'd better swerve).

In measuring SA, the participant is placed in a simulated scenario and then at random and unpredictable times the scenario is briefly frozen and is asked a couple of brief questions. The questions get at various levels of SA: "What are you seeing?" What will happen next?" and so forth. Endsley's seminal research (Endsley, 1995) demonstrated that brief time freezes do not substantively affect performance and do not disengage the participant form the scenario. In the domain of piloting, Endsley (2006) showed that a measure of situational awareness is a better predictor of performance at simulator tasks than number of hours of flying experience. Interestingly, the concept of SA was first proffered by fighter pilots, who referred specifically to the need for a pilot to "get inside the head" of the adversary in a dogfight. (This would be level 4 SA.) (See Endsley, 1989.)

Endsley and Robertson (2000) and Shebilske, et al. (2000) reviewed the literature on SA training. The levels of SA are useful as a framework, for analyzing the frequency of errors (especially pilot errors) at the different SA levels, comparing error rates for better and worse performing pilots and aircrews. Such an analysis is suggestive of what the training needs might be for a pilot or team that is performing at a less-than-proficient level (e.g., practice at estimating risk in certain situations).

Endsley and Robertson (2000) identify low SA as one of the key factors in aviation failure. Because it is so important to the success of pilots, methods for training and evaluation SA are imperative to the success of aviation training programs.

The authors posit that SA training can be developed via two main methods. The first method is to examine the specific ways in which errors occur, based on surveys, records, and experiments. The second method is to examine how pilots maintain SA, and the differences between pilots who do maintain SA and those who do not. The authors continue by providing examples from the literature, citing studies that used techniques such as the critical incidence method in order to determine how SA is maintained in practice.

Based on the reviewed studies, the authors provide a number of methods by which SA can be improved. Task management skills allow pilots to deal with interruptions and workload that would otherwise reduce SA. The development of comprehension allows pilots to properly determine the consequences of various occurrences during flight, while the ability to project and plan for future events is closely tied to workload and SA. Additionally, individuals with high SA engage in information seeking and self-checking actions.

Given that effective pilots exhibit these skills, Endsley and Robertson propose a number of interventions to ensure the improvement of SA. Higher-order cognitive skills training can be used to train skills necessary to the development of SA, such as contingency planning,

information sharing, and filtering. The authors argue that training these skills will also provide increases in SA. Extensive pre-flight briefings also provide pilots with a more comprehensive mental model of their task, increasing SA. During flight simulation, techniques such as the Situation Awareness Global Assessment Technique (SAGAT) can be used to provide pilots with more feedback about their own SA quality, engendering metacognitive skills.

Endsley and Robertson note an outstanding research need: Few research programs have attempted to train specifically for SA, across the SA levels (attention management, high-level cognitive skills. She notes that the SA levels could be use to structure feedback. Related to research on sports (and the education of perception and attention), Endsley notes that training can emphasize the perception of important cues and cue patterns signaling when a situation is typical or is atypical. This fits similar recommendations about feedback and training from other researchers.

There is one project that has attempted SA training, a project on the training of teams of aircraft maintenance personnel (Endsley & Robertson, 1996). An analysis of the "SA Requirements" for teams served as a useful framework for delineating the training areas, including: shared mental models of situations, failures to share information across teams whose tasks interacted, the need for the establishment of shared goals across teams. The resultant SA training course was administered at the maintenance bases of a large commercial airline. Following the course, participants rated the course as uniformly "very useful" for increasing safety and teamwork, and would result in considerable change in how the maintenance teams operated. These ratings were maintained in a one-month follow-up, which the researchers interpreted to mean that there was a change in the work and a positive effect on performance and the training was "highly successful."

In applying SA notions to "human-centered training," Shebilske, et al (2000) noted that one can apply the finding from cognitive science that deliberative analysis characterizes the reasoning of trainees whereas automaticity characterizes the reasoning of high proficient practitioners. The implication of this would be that initial training should not be overly dependent on automation but rather should allow the participant the opportunity to learn the procedures that might, in the operational context, be handled by the automation. This notion would seem to contradict the recommendation that training should emulate the operational situation to the extent possible, but this is a matter to be resolved by research, specifically on the question of to what depth and extent do trainees (or proficient practitioners, for that matter, need to know what the computer is doing "deep down inside." Additional recommendations for training include training to allow practitioners to develop good mental models and training in the management of attention. Such recommendations would not derive uniquely from SA notions, of course (see Damos & Wickens, 1980; Gopher & Brickner, 1980).

2.3.9 Training for High Proficiency

A prominent theme in Expertise Studies is that high proficiency stems from self-assessment and self-directed learning, deliberate practice, and the self-assessment of the development toward expertise. These depend on learning environments that promote progression of proficiency (Fletcher, 2009). There is relatively little research on training at the high end of proficiency. Interestingly, the Ericsson, et al. (2007) *Cambridge Handbook of Expertise and Expert*

Performance includes no discussion of training or training issues. This links directly to the core problem motivating the present Report.

Practice, Practice, Practice

One of the foundational laws of psychology is Aristotle's law of frequency, that the more frequent an experience or association, the better will be memory for it. This idea spans the entire history of psychology, leading to associative trace strength theories of memory, theories of memory decay, and other notions and research paradigms. The law of frequency is arguably true, and applies as well to the learning of experts as it does to the learning of the newborn.

In sports, the majority of a performer's time engaged in the task is preparation. Sports performers often engage in competition-specific preparation which allows them to prepare in such a way that mirrors the competition and sufficiently adapt to its contextual features (Eccles, et al, 2009; Vicente, 2000). A general finding from studies of expertise broadly is that the *amount of practice* is the single greatest determinate of superior performance, followed by specificity of practice and motivated of practice at difficult tasks (Schmidt & Lee, 2005; Ericsson, 2003).

Motivation

A research finding from many studies spanning decades, is that high proficiency is achieved only after years of sustained and motivated effort, which Thorndike (1912) called "practice with zeal." The phenomenon has often been noted (Bereiter & Scardamalia, 1993; Ericsson, Charness, Feltovich & Hoffman, 2006; Hoffman & Militello, 2008). The core idea has even made its way into the popular press in stories told about the nature of talent versus ability (e.g., Gladwell, 2009; Shenk, 2010). "Amateurs work until they get it right; professionals work until they can't get it wrong" (General Motors Corporation television commercial, August 2006). "Apprentices make the same mistake twice; experts make the same mistake once" (Guillermo Alvarado, 2006). The central implication for training is the need to emphasize motivational factors.

The role of motivation in achieving high proficiency is highlighted in the literature on organizational learning (e.g., Center for Applied Systems Studies, 2010). This is referred to by the notion of the "reflective practitioner" (Schön, 1983) who can improvise or create hybrid options if an existing set of options seems to be inappropriate. The reflective practitioner gains this capacity by analyzing their own ability to deal with situations.

Trainees need to have a sense of achievement to balance a sense of failure, which might be more impactful because the work is cognitively difficult and hence trainees might be especially prone to failure in the early phases of instruction."Research indicates pervasive effects for the motivational components on self-regulatory processes, learning, and performance" (Kozlowski & DeShon, 2005, p. 6-7).

Ericsson's "expert performance approach" translates these ideas into the concept of "deliberate practice" (see Ericsson, et al., 1993). The approach consists of two ideas. First, it defines expertise as superior performance at representative tasks. Second, it asserts that claims about expertise can only be made with reference to individuals who have been empirically demonstrated to show reliably superior performance under controlled circumstances. These operational definitions are important from the standpoint of academic research.

Problems with this "approach" include the following:

- It does not adapt to application situations where the expert's performance cannot be brought under laboratory control.
- It does not adapt to domains in which the principal tasks (and hence the performance measures) are ill-structured and problem solutions are well-defined.
- It does not adapt to domains in which tasks are always changing.
- It does not adapt to domains in which there are only a few "experts."
- It is mute with regard to proficiency scaling, apart from dividing the world in to people who are experts and people who are not.
- It ignores additional and important elements within the conceptual definition of expertise, specifically, that experts can perform well at tough cases, and can create new methods and strategies "on the fly."
- It tacitly devalues the study of expert knowledge,
- It tacitly devalues the study of studying expert reasoning strategies.

Ericsson would likely disavow the last of these assertions, since studies using this "approach" have revealed strategies (e.g., strategies for managing working memory load on the part of expert memorizers of long strings of digits). But the "approach" as stated reflects its origins in the paradigm of academic research on human performance, rather than the paradigm of cognitive work analysis or human factors. Our reason for calling out the ostensive limitations of the "approach" is that if expertise is achieved only after deliberate practice (the "10-year rule of thumb), then acceleration would not be possible.

Training for Adaptivity

Kozlowski and DeShon (2005) reported a series of studies on how individuals and teams adapt, including an analysis of interventions intended to enhance adaptive capacity. They present a model in which adaptive capacity is said to depend on the following factors:

- Goal representation. How individual and teams conceive of their goals will influence their learning and adaptation strategies.

- Self-regulation. Complex cognitive work requires self-regulation across multiple tasks and goals, especially in teamwork contexts.

- Resource allocation. How can individuals and team be trained to optimally allocate resources across multiple asks and goals?

Instruction that prompts trainees to approach learning as an effortful and mindful process ("active learning") are useful in training for complex cognitive work, generally associated with improved skill acquisition and increased adaptivity. Trainees need to think about their own strategies ("mindfulness training"). Trainees need to focus on mastering tasks, rather than getting individual problems right ("mastery training"). To counterpoint the emphasis on the role of practice, we hasten to point out that the basic aptitude or intelligence, and the background knowledge of the learner certainly place some bounds on training effectiveness and outcome. A study that reviewed measures and results found for predicting on-job performance in the U. S. military from 1952-1980 (Vineberg & Joyner, 1982) found that job knowledge tests (of prior knowledge) were a useful predictor of performance, that aptitude was the most utilized predictor in the design of training plans, and that supervisor ratings were the most used criterion, useful in jobs where social skills were important.

Interestingly, the Vineberg and Joyner report anticipated current concerns. The authors found a need to measure or evaluate skill at responding to "situational requirements" which we would refer to as adaptive capacity. Also, the authors recommended training and testing based on "miniature training and assessment centers," and the use of self-studying as a measure, reflecting perhaps the notion of deliberate practice. While in the present Report we have emphasized training by scenarios and simulations as a means for acceleration, Vineberg and Joyner (1982) saw it as a way to assess the initial competence level of trainees and predict their performance or success following training:

> At least two approaches to prediction would appear to take some advantage both of the point-to-point strategy and of the efficiency of training performance as predictor: (1) the use of miniaturized training and assessment centers in which prospective trainees can be tested in a sample of work activity, and (2) increased focus on individualized, self-paced training as a predictor. If the time for training and observation in the center were kept brief, the former approach could be used for entry screening for military service (performance in self-paced training could not, of course, be used for entry screening) (p.24).

Psychological Support Skills

High proficiency in all domains involves meta-cognitive skill, as captured in the notion of the "reflective practitioner." The training of self-reflection is referred to as Psychological Support Skills Training. Is involves practice at mental rehearsal, self-talk (that is, mindfulness) goal-setting, and goal focus versus performance focus (Eccles & Feltovich, 2008).

These skills can be trained and learning, for instance, trainees can be taught to counter negative self-talk, that is, to recognize when their self-talk is critical and self-defeating, and focus instead on looking for cues to positive action. Eccles and Feltovich speculate that "Novices who learn and apply psychological support skills experience accelerated learning" (p. 53).

Source of Instructional Materials

One source of materials for accelerated training will be scenarios, as discussed above in section 2.3.6. As we asserted in the introduction to this Section of this Report, expertise is the "gold standard" for training, it is the source for training materials, and it is a goal for accelerated learning. A consensus in the human factors and cognitive engineering communities, is that Cognitive Task Analysis for specifying what knowledge, strategies, skills, and attitudes is required for conducting a tasks, and, hence is required for the formulation of training and instruction (Schraagen, 2009). Indeed, cognitive task analysis emerged in instructional design research (for the military) (see Hoffman & Militello, 2009).

2.3.10 Conclusion

The fact that learning, training and instructional design are so highly complex, with multiple factors that interact, makes if very difficult to compose anything like a recipe for instructional design for proficiency training. Indeed, the complexity is so daunting as to bring some to near despair. For example, Dodd (2009) discussed the implications of moving target problems for

military training and "end-to-end" evaluation. In an ideal situation, one would be able to trace the effects of instruction, from the very beginning, noting its effect across the entire span of learning various knowledge and skills, right through to final operations performance. Reasons why this is not possible are:

- The time taken for the changes due to training to percolate through to operational effects can be long and involves complex interactions with other functional attributes, such as organizational constraints and operational pressures.

- There is no straightforward track through the formal process of lessons-learned enabling us to give credit to any particular input (or lack of input) for any specific observed outcome.

- Operational outcomes are so contextually and circumstantially driven that they defy backwards-looking interpretation necessary to understand cause-and-effect linkages.

- Operational effectiveness outcomes are tied to scenarios making it impossible to get representative coverage permitting generalizations that specify which training inputs are effective in meeting which possible or future operational challenges.

"So we are often reduced to stating the obvious: that doing no training or education would result in poorer operational outcomes" (Dodd, 2009).

Others are more hopeful, especially with regard to a vision for acceleration.

Further discussion of training to high proficiency appears later in this Section, in subsection 2.7, reviewing the existing examples of success at accelerated learning. In the Section 6.0 that concludes this Report, we will carry over the positive generalizations that can be confidently asserted based on the literature on training that has been reviewed in this Section.

2.4. Transfer

The major theory of transfer is the "common elements" theory. Based on this idea, one would say that training should minimize the transfer distance from training to workplace. Recent research is suggestive of the conditions that promote transfer, such as the judicious use of particular kinds of feedback (Schmidt & Bjork, 1992). However, performance issues go beyond transfer from the classroom to the operational context. Simply "working at a job" does not promote progression along the proficiency continuum. Unless there is continuous deliberate practice at difficult tasks, the only thing one can do "on the job" is forget and actually experience degradation of skill.

Furthermore, the current challenges for military training involve two different sorts of transfer. One is *transfer across mission types.* An example would be an infantry commander who knows traditional warfare who is asked to develop tactics for an insurgency operation. The second challenge is *transfer across responsibilities.* An example would be a Warfighter skilled at F-16 engine maintenance who is promoted to a supervisory position. Since different skill sets would be involved, one would need to train for the new role, and not just assume transfer would or might happen. Motivation, intelligence and other mediating factors would be enabling conditions perhaps, but not guarantees of transfer. The supervisory position might be in the area of aircraft maintenance, but that too would be an enabling condition and not a guarantee of transfer.

Transfer of learning or training has been a salient issue in recent discussions of national

educational policy, given its direct pertinence to the complexification of the modern workplace, the emergence of a workforce which does not define itself in terms of careers with single employers, and the general need for a workforce that is capable of critical thinking (see Haskell, 2001). In other words, for the economy and for organizations to be competitive, the workforce must be capable of transfer of learning (Broad & Newstrom, 1992).

There are a number of different meanings of "transfer" in the literature. Some modern researchers refer to the transfer of a single acquired skill from the training context to the performance context. This meaning of "transfer" is a reference to the durability of training or the retention of some skill or level of capability, e.g., how long the learner can accurately retain and utilize information. Many studies that refer to transfer compare performance in a learning context to performance in a subsequent evaluation context, when the tasks or problems remain essentially the same. This meaning of "transfer" is rather the same as the notion of skill retention. For transfer in this sense to be effective, "the training must incorporate the complete set of transfer task requirements, including any secondary task requirements imposed" (Healy, et al., 2005, p.11).

Research on transfer, in the sense of durability or retention has resulted in some useful general findings. One is the phenomenon of "desirable difficulty" which was discussed above in this Report in Section 2. Things that make learning difficult facilitate transfer (in the sense of retention of capability) to a new task as well as long-term retention of the original task. By the training difficulty principle, any condition that causes a desirable difficulty during learning facilitates later retention and transfer (Bjork, 1994; McDaniel & Einstein, 2005; Schneider, Healy, & Bourne, 2002). Another finding is that for optimal performance, the entire configuration of task requirements during training needs to match those in the transfer context as closely as practically possible. By the specificity of training principle, retention and transfer are depressed when conditions of learning differ from those during subsequent testing (Healy, Wohldmann, Sutton, & Bourne, 2006).

In this literature, learning "is assumed to refer to that set of processes occurring during the actual practice on the tasks of interest, as assessed by performance measures taken at that time, whereas retention is seen to involve the set of processes that occur after practice is completed, during some retention interval, and prior to a retention test" (Schmidt & Bjork, p.209). Schmidt and Bjork argue that retention should be viewed as a measure of the effectiveness of learning and not as a phenomenon of transfer.

Haskell (2001) has specified a number of different meanings of "transfer." These are listed in Table 2.8.

Table 2.9 Different kinds or senses of transfer (after Haskell, 2001).

Content-to-Content	Applying knowledge in one content domain to aid the learning of knowledge in some other content domain.
Procedure-to-Procedure	Using procedures learned in one skill area to work problems in some other skill area.
Declarative knowledge-to-Procedural knowledge	Book knowledge or knowledge of concepts and principles learned about an area aids in the learning of skills, strategies or procedures in that same area.
Procedural knowledge-to-Declarative knowledge	Experience with the skills, strategies or procedures in an area aids in the learning of conceptual knowledge in that same area.
Transfer of Self-aware Strategic knowledge	Knowledge about one's own reasoning or strategies is applied from the original domain of learning to some other domain.
Cross-subdomain transfer of declarative knowledge	Knowledge of a concept or cause is generalized across subdomains (e.g., lightning as a form of electricity).
Cross-subdomain generalization (also called vertical transfer)	Knowledge of a particular is generalized across subdomains (e.g., learning about the cause of a particular war facilitates the learning about the causes of war in general).
Cross-domain transfer of declarative knowledge	This includes transfer based on analogy. It also includes the "usefulness of useless knowledge," as in trivia quizzes.
Lateral transfer of skill	Learning one perceptual motor skill facilitates the learning of some other very similar perceptual motor skill (e.g., ice skating-roller skating).

For the purpose of this Report, it is sufficient if we consistently distinguish:
• Transfer of knowledge (in the sense of content knowledge)
• Transfer of perceptual-motor skills, and
• Transfer of reasoning strategies.

Equally important is to separate transfer from retention, thus we define transfer as:

> *When knowledge skill or strategy learned in one context or learned for one problem/task type is successfully utilized in learning or performance in some other context or for some other problem/task type, where either the contexts or the problem/tasks types are both similar and different.*

There is ample evidence, both scientific and personal, that transfer does happen. For instance, one participant at the Working Meeting said: "*Preparing for the B-1 after flying the B-52. Not a*

great jump. Right after my quals I was told I would be an instructor! There are also experiences of negative transfer. In a study of automobile driving skill of Americans driving in the United Kingdom, reports from drivers typically referred to phenomena of negative transfer—stories about how hard it was, the problems experienced, etc. The actual data on performance showed positive transfer, however (Singley & Anderson, 1989). (In a formal demonstration one would have to show that the Americans achieved a base level of acceptable performance in less time than it had taken for them to initially achieve that level when learning to drive in the U.S.)

There is also surprising evidence that transfer does *not* happen. Shanteau et al. (2002) conducted an evaluation of the performance of highly expert livestock judges who rate animals on such dimensions as breeding quality and meat quality. The researchers found that skill at discrimination for swine does not transfer to skill at discrimination for cattle (and vice versa). "Expertise is spectacularly narrow." The surprise here is perhaps a reflection of the naïve and wrong assumptions that we non-experts make in apprehending the task without benefit of the experts' skill acquired through perceptual learning.

In retrospecting about the history of research on training across his own career, especially with respect to his classic book *Training in Business and Industry* (McGehee & Thayer, 1961), Paul W. Thayer (2000) noted that "We have gone from a simple view of the learning and transfer of training processes to a much more complex one." (p.1). He noted that earlier work on training considered only single and relative simple tasks, and considered only simple contrasts, such as that between part and whole training, and that between massed versus distributed practice. A distinction was not made between things that might enhance or inhibit transfer during training, things that might enhance or inhibit transfer from training to the job, and things that might enhance or inhibit transfer on the job. He acknowledged that some things they postulated were simply wrong. For instance, while the notion of overlearning was considered, it has only become clear in years since the 1960s that overlearning is a prime determinant of decay. Certainly off the radar in 1960 was team training and the additional layers of complexity this adds to the topic (see Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995).

2.4.1 Demonstrating Transfer: Simple Perceptual-Motor Tasks

Much of the research by Robert Proctor and his colleagues has focused on transfer of newly acquired associations in tasks that require a rapid choice response to a stimulus (Proctor & Vu, 2006). In the prototypical procedure, a two-choice reaction task of pressing left and right response keys mapped incompatibly to stimuli in left or right locations (e.g., press "left" key to a stimulus that appears on the "right") is first performed. This is followed after a delay by performance of another two-choice reaction task in which subjects respond to a non-spatial stimulus attribute (e.g., color; the *Simon task*) and stimulus location is irrelevant. Thus, the spatial mapping used in practice is task-irrelevant in the transfer task. Without such practice, responses are faster and more accurate when the stimulus and response locations correspond, which defines the *Simon effect*. However, after performing the incompatible-mapping task, the advantage of the spatially compatible responses in the Simon task is eliminated. This outcome implies that participants acquired incompatible stimulus-response associations and transferred them to a subsequent task even though they were no longer relevant.

Through manipulating several variables, the researchers have found that:

- The incompatible stimulus-response associations are retained for at least a week.

- The strength of the associations, as implied by the magnitude of the transfer effect, increases as the number of practice trials increases.

- These associations have both modality specific and general components, as practice with auditory stimuli produces some transfer to a visual Simon task.

- With extended practice, more abstract rule-like procedures are acquired that generalize, for example, across different spatial orientations.

- Practice with left and right pointing arrows transfers to stimuli varying in left and right locations, and vice versa, implying reliance on common visuospatial codes.

- Arrows also show some indication of producing transfer to location words (and vice versa) after more extended practice, whereas spatial locations do not, suggesting that arrows also activate verbal-spatial codes common to verbal stimuli.

- No reduction in transfer occurs when perceptual features of response devices used in the practice and transfer sessions are altered, but significant reduction occurs when responses are executed differently (by pressing keys with two hands or moving an index finger to a response key) in practice and transfer sessions. These results suggest that motoric or procedural components are more salient than perceptual components.

Basic tasks of this type can be used to investigate and test characteristics of associative learning. The results can be used to develop and test quantitative and computational models of skill acquisition, retention, and transfer for predicting training effectiveness.

2.4.2 Demonstrating the Failure to Transfer: The Domain-Specificity of Knowledge and Skill

Just as there are studies showing positive transfer, there are studies showing that declarative knowledge does not transfer across domains (except in analogical reasoning) (Haskell, 2001). A number of studies have shown that experts' knowledge but also their skills are domain-bound (e.g., Beach, 1988; Chiesi & Evans, 1988; Groen & Patel, 1988; Spilich, et al., 1979). Thus, for example, a study of chefs found that they could easily do the math needed to convert a recipe designed to feed 12 into a recipe designed to feed six, but could not do so well, using the same basic mathematical operations, to convert the prices of meals.

While an expert might have highly refined and differentiated categories of concepts within the domain, their knowledge of things outside the domain is not so broad or differentiated (Chase, 1983; Chiesi, et al., 1979; Glaser, 1987; Scribner, 1984). In addition, the strategies of expert reasoning are shaped by the tasks and contexts that are involved in the domain (Greeno, 1978; Scribner, 1984). Thus, for instance, performance at card games by highly practiced individuals can be significantly disrupted by even minor changes in the game rules (Sternberg & Frensch, 1992).

2.4.3 Promoting Transfer by Exposure to Variants

Task variability during training can produce interference and, thus, retard initial skill learning, but often enhances ultimate performance (see Healy, 2007). It is well established that the learning curve during training (that is, time-to-criterion) can be affected if the practice involves experience with a variety of kinds of tasks, problems or test cases, sampling representative tasks and also capturing the range of problems or test cases on the most important dimensions, especially difficulty. The ultimate benefit for variable training is found even when the task used in testing differs from those used during variable practice and is the same as that used during constant practice. Healy (2007) cites a study in which children practiced the tossing of beanbags. Practice that varied the target distance led to better accuracy at test on an intermediate target distance than did practice that was restricted to that intermediate target distance.

2.4.4 Motivation and Transfer

It has been demonstrated that incentives can have a strong effect on transfer. Brennan, et al. (2009) examined whether transfer of training would be improved by incorporating case variations during the initial training. This study examined whether transfer of training would be improved by incorporating various during the initial training. Participants were given a visual search task of inspecting luggage for weapons. Participants were shown a series of objects to distinguish weapon from non-weapon (signal from noise). Participants were broken down into five groups, those that were given positive "hit sensitive" incentives (more points for correct target identification), negative "miss sensitive" incentives (deductions for incorrect target identification), "equal costs" (equal points for hits and misses), no incentives (no points awarded), and a control group that was self-trained and did not receive initial, guided training and were not primed by specific targets from the experimenters. Participants were measured on their "hit rate", "false alarm rate", and their confidence in choices. In turned out that the "control group" of self-trained participants showed superior performance, demonstrating the highest hit rate and the lowest false alarm rate. They also had lower confidence on false alarms and higher confidence on hits, which is also a superior outcome. Interestingly, the "self-trained" group had the lowest performance during training, yet they had greatest degree of transfer. Aside from the self-trained group's superior performance, the study showed that groups that received incentives performed better than those that did not. (It should be noted that the participants pool were university students—who are unlikely to have been luggage inspectors—and the exercise incorporated very low stakes; a points system that resulted in a maximum gain of only $7.00.)

2.4.5 The "Common Elements" Theory

The initial meaning of "transfer," historically speaking, is when the learning of a skill results in improved learning of some other skill that is both different from and yet similar to the first learned skill (e.g., fewer trials to criterion on learning skill 2 than on learning skill 2). The primary theory of transfer, mentioned earlier in this Report, is the "common elements" theory first proposed by Edwin Lee Thorndike:

> One mental function or activity improves others insofar as and
> because they are in part identical with it, because it contains

> elements common to them. Addition improves multiplication
> because multiplication is largely addition... (1906, p. 243).

This theory emerged in the context of a theory that all learning was the formation of specific stimulus-response habits, and research on transfer of simple perceptual-motor skills (e.g., typing, pursuit rotor tasks). There was concern, of course, with educational applications, such as the possibility of transfer of language skill (e.g. the learning of Latin will increase the student's ability to learn French). The common elements theory still serves as a guide to research, though the topics and methods for study have expanded considerably since Thorndike's pioneering studies (Thorndike & Woodworth, 1901). For instance, there has been a burgeoning of research on problem solving by analogical transfer (see Hoffman, Eskridge & Shelley, 2009).

The common elements theory leaves open the matter of what constitutes an element. Thus, we can find the theory manifested in computational models in which the common elements are production rules that apply to different kinds of problems (Singley & Anderson, 1989). With the emergence of cognitive engineering and studies of human-computer interaction there was another extension of research on transfer, showing positive transfer from learning to use one software system to learning another if the two share the functionalities (e.g., of text editing) (see Singley & Anderson, 1989). However, if the functionalities are similar but the display and input-output mechanisms are very different, there can be little transfer. Jahn, Krems, and Gelau (2009) showed only slight positive transfer after 100 trials at using one in-vehicle route-planning GPS system to using another.

This lack of transfer reflects the differences between the systems in controls, in displayed information, and in optimal monitoring procedures. The differences in controls alone may have been sufficient to prevent transfer, as results from laboratory studies suggest (e.g., Pashler & Baylis, 1991). Both greater positive transfer as well as negative transfer might occur between more similar systems (p. 148).

What this consideration means is that transfer cannot be analyzed separately from a notion of contextual dependency. This leads directly to the notion of "transfer appropriate processing."

2.4.6 Transfer-Appropriate Processing

Transfer from the training context to the evaluation or performance context depends on the similarity of the tasks comparing the two contexts (e.g., Adams, Kasserman, Perfetto, Bransford & Franks, 1988; Morris, Bransford, & Franks, 1977; Needham & Begg, 1991; Perfetto, Bransford & Franks, 1983). In a study by Healy et al. (2005), participants executed a time estimation task. Durability of performance over long delays could be achieved if the procedures were exactly duplicated from trial to trial, but when the tasks were changed even slightly from trial to trial, very little transfer occurred. Thus, for transfer to be effective, "the training must incorporate the complete set of transfer task requirements, including any secondary task requirements imposed" (p.11).

In its initial incarnation, the finding of transfer-appropriate processing was used to argue against tenets of levels-of-processing theory (Craik & Lockhart, 1972) and the supposed encoding strength of deeper processing (Morris, Bransford, & Franks, 1977). Some had argued that, rather than the depth of processing, "it is the qualitative nature of the task, the kind of operations carried out on the items that determines retention'' (Craik & Tulving, 1975). Original

investigations of this theory focused on recognition and recall, but it has been greatly expanded upon to account for dissociations in implicit and explicit memory tasks for verbal and pictorial stimuli (e.g., Roediger & Blaxton; 1987; Roediger, Weldon, & Challis 1989).

Transfer Appropriate Processing theory has additionally encompassed more complex cognitive processes. For example, within problem solving research, TAP theory supports the notion that initial strategies influence later problem solving and that the matching of strategies during learning and test facilitates overall problem solving effectiveness. This research has been conducted on simple puzzle tasks (Adams, et al. 1988) but also on more complex tasks such as learning to use graphics software (Caplan & Schooler, 1992). Finally, TAP theory has been integrated into the tenets of Problem-Based Learning (Hmelo, 1998).

More recently, TAP theory was used to account for varieties of findings in category learning. Markman and Ross (2003) suggest that:

> ... category acquisition occurs in the course of using categories for different functions. The particular information that is acquired about a category member in the context of carrying out a particular task depends on the information that is required to carry out that task successfully... categories are critical for a wide variety of tasks, and one would hope that category-learning research can provide some further ideas of category learning and representation to these areas in which category use is so important (pp. 609-610).

From the perspective of understanding proficiency and its acquisition, what is important to recognize with TAP theory is that synchrony between processes engaged during the time of learning or acquisition of a given material and the eventual use of that material is crucial for performance across a surprising number of tasks (Roediger, et al. 2002). Contextual factors, therefore, are critical to learning and retention over and above what is typically described in the memory literature. More specifically, TAP theorizing is most cogent with respect to acceleration in that TAP theory has consistently identified that recapitulating specific encoding and retrieval operations enhances performance.

This leads directly to the question of training for transfer in domains of high complexity. The implication is that ecological validity of the training content and training processes will permit transfer, in the sense of performance carry-over from the training to the operational context. Fidelity per se is not the critical feature. A substantial body of research suggests that only some aspects of the training need to be faithful to the operational setting. For example, research has found that use of high physical fidelity simulations in training, had very little effect on actual job tasks compared with lower-fidelity simulations (Taylor et al., 1993). Similarly, research has successfully used low fidelity PC based simulations to train complex individual and teamwork skills (Gopher, Weil, & Bareket, 1994; Jentsch & Bowers, 2001; Prince & Jentsch, 2001; Taylor et al., 1999). The level of fidelity needed should be driven by the processes and activities in the task (Salas, Bowers, & Rhodenizer, 1998; Salas & Burke, 2002). This idea has led training research to consider the relevance of *cognitive fidelity* in today's synthetic task environments (see Durlach, & Mavor, 1995; Entin, Serfaty, Elliott, & Schiflett, 2001).

2.4.7 Within-domain Transfer Across Problem Types

A focus of research in Expertise Studies is the acquisition of skill in domains where problems are complex, often ill-structured and highly reliant on knowledge. The transfer question is whether knowledge particular to some sub-domain can be utilized in solving problems in some other sub-domain. While this echoes the Thorndikian definition of transfer, as between two skills that are both similar and different, the focus here is on knowledge. Feltovich, et al. (1992) investigated the role of complex knowledge in medical clinics. The hypothesis from common elements theory would be that:

> Transfer (and knowledge application) requires that a common structure between different contexts be detected, imposed, or assembled, so that the applicability of a pertinent body of knowledge in the different (or perhaps just differently *appearing*) circumstances can be signaled (p. 214).

It is their contention that achieving the ability to derive a common structure across varying context becomes more difficult as tasks become more complex and as the structure of the task becomes increasingly irregular, ill-defined, or less orderly. Ill-structured domains are those in which multiple, interacting concepts may apply to the same case, and the same concept may apply across a variety of cases. The learner must be able to detect the common structure of concept across cases and be able to understand the ways in which the context changes the nature of the concept.

If the findings in Expertise Studies and the tenets of Cognitive Flexibility Theory are true—that experts are able to adapt to novel cases—then the transfer of capability across different-yet-similar problem types across subdomains but within a single within a domain is a *necessary* aspect of high proficiency. Fundamental to the achievement of robustness, resilience and adaptivity is the opportunity to practice at problems that stretch current competency (Feltovich, et al., 1997). Professionals must acquire knowledge and reasoning skills that pertain to critical domain goals but which must be exercised in widely differing situations or contexts.

Current challenges for military training involve two different sorts of transfer. One is transfer across mission types. An example would be an infantry commander, who knows traditional warfare, who is asked to develop tactics for an insurgency operation. The second challenge is transfer across responsibilities. An example would be a warfighter having a skill at maintenance of an F-16 engine who is promoted to a supervisory position; another example is the focus on every Soldier or Airman becoming a "sensor," requiring the infantryman to understand the rudiments of Intelligence data collection. Since different skill sets would be involved, one would traditionally need to train for the new role, and not just assume transfer would or might happen.

In their paper on the need for "adaptive expertise" in the changing workplace, Smith, Ford and Kozlowski (1997) argued that little hope should be held out for transfer of general knowledge to specific tasks or skills in complex cognitive work, but hold out hope for training and transfer benefits from new methods such as advance organizers, discovery-based learning, error-based learning, varied practice, and cognitive mapping exercises to build mental models.

2.4.8 Generalizations About Transfer

As the above discussion shows, it is difficult to latch upon generalizations concerning transfer. Thorndike's initial studies of learning and transfer were based on the "doctrine of formal discipline" that was entailed by the associationist view that learning is the strengthening of stimulus-response bonds (a version of Aristotle's law of frequency). Studies did not clearly support the prediction this theory makes for transfer. For instance, one of the early studies involved training students to estimate the length of lines less than 2 inches long and then transfer to estimating the length of lines grater than 6 inches. There was no positive transfer apparent in the data (Mayer, 2003). At higher levels of learning, no transfer was found, for instance, from the learning of Latin to learning in other languages at the high school level. On the other hand, learning to read a passage while crossing out tertian letters lent positive transfer in reading passages while crossing out other letters (Thorndike & Woodworth, 1901). Ironically, Thorndike's initial doctrine of formal discipline motivated the "Latin school movement" which argued that learning Latin promotes the learning of English, and learning in general. Transfer is specific, and not general.

Pillsbury reviewed the research on transfer in 1926, with regard to the educational doctrine of formal discipline, for example, that training memory for one task context will train memory for all other task contexts. He cited an extensive study in which university students were tested for skill in memorixing poetry and then given extensive practice at memorizing nonsense material, after which they took another poetry memorization test. He found only modest evidence for improvement. Subsequent experiments, with control conditions, failed to replicate this result and attributed better performance on the second test to simply having had taken the initial test. Interestingly, Pillsbury advocated that learning should be by "ideas" rather than by "rote," a principle echoed in essentialy all modern theories of meaningful or active learning, and in educational resarch as well (e.f., Cognitive Flexibility Theory). Pillsbury notes that any positive transfer might not necessarily be due to the training of a common skill or "faculty," but might instead be due to the adoption of some general rule or habit (or even something as simple as learning to be more careful when in the psychology laboratory!). On the other hand, some remnant of common elements theory is preserved in the findings Pillsbury summarizes. Learning Latin can lead to modest improvement in skill in English. This is commonly explained because of similarities of grammatical and syntactical rules, but Pillsbury argued that Latin is heavily case sensitive versus syntax-denendent, and so any transfer is almost certainly due to the sharing of words by word origins. To paraphrase Pillsbury (pp. 308-313):

> Biology training improves skill at observing living materials; studying descriptive geometry improves skill at solving geometry problems; training in special skills does not improve overall performance in school. Overall, the major variable that stood out in the resarch findings, even in the early 1900s, was general level of intellectual ability. While it is desirable to get training in special fields, the student should be prepared to find very little application for much of his knowledge.

One resolution to the mystery is to recognize that there are complex interactions. For instance, there is a so-called "paradox" of transfer. Certain training practices, such as presenting learners with an increased amount of information, or increasing the pace of training, can enhance learning during training but may not promote high levels of performance subsequently in the operational

context (the "durability" meaning of transfer) (Schneider, Healy & Bourne, 2002). Practices such as increasing task variability will interfere with performance during training, but enhance transfer (Wulf & Schmidt, 1988). Reasons for these phenomena include a distinction between learning that allows for immediate but temporary recall, and learning that allows for longer-term recall that is procedural or skill-like rather than purely declarative of knowledge-like.

In concluding her summary of research pertinent to transfer, Healy (2007; Healy, et al., 2003) argues that transferring the skill to new situations is often difficult but can be promoted by following a number of training principles: Employing deliberate practice, increasing the variability of practice, adding sources of contextual interference, using a mixed practice schedule, distributing practice in time, and providing process and outcome feedback in an explicit analysis of errors.

2.5 Decay and Retention

The challenge of achieving and maintaining high proficiency is compounded in the military by such practices as collateral assignment, redeployment (e.g., rapid skill decay on the part of pilots creates a need for expensive re-training), inadequate or ad hoc mentoring, and the drive for "just-in-time" training.

2.5.1 Introduction

Decay and retention of both perceptual-motor skills and declarative knowledge have been extensively studied by psychologists using methods including recall and recognition. Indeed, the experimental study of learning-decay curves marks the beginning of the experimental psychology of learning (Ebbinghaus, 1885; Woodworth, 1903, 1938). Also in the learning literature, memory decay is one of the main hypothetical causes of forgetting (e.g., Anderson, 2000; Bransford, 1979). Particularly pertinent to the present study is research on retention of knowledge or skills following periods of non-use, which we call "hiatus."

Retention of skill is an issue in many domains of professional activity. For example, special efforts and procedures are needed to help physicians maintain skill and continuously update their knowledge (Davis, 2009). Medicine contains formal, mandated procedures for the conduct of continuing medical education, including such things as workshops and seminars, but also periodic processes of recertification. In parallel, there are efforts to research and document of "best-evidence" practice in medicine, dealing with diagnosis, procedures, treatment, and management. Continual learning must be aimed at preventing medical error related to the lack of practice. These studies are conducted by various bodies, including venues of traditional scholarship and major national studies (e.g., by the Institute of Medicine). They present prescriptions for how to support continuing medical education.

As the technology and capability of military operations have increased, so too has there been an increase in the number of jobs/roles that are complex and knowledge intensive, significantly raising the baseline or benchmark for minimal proficiency. Indeed, it is often said that in complex sociotechnical work systems (of all kinds) *expertise is a must* because decisions are high stakes and high risk. Thousands of military jobs can still be defined largely in terms of "common tasks" and associated procedures, but thousands can only be defined in terms of the need for significant levels of knowledge and significant skill. But of those thousands that are still

largely definable in terms of tasks, they too are morphing, as is witnessed in the diverse set of activities that are new to the traditional infantry. The very concept of "task" has been questioned for its appropriateness. It is no longer the case that jobs can be defined in terms of "tasks" defined as fixed sequences of activities. Workers engage in context-sensitive, knowledge-driven choice among activities (Rasmussen, 1986, 1992). In other words, there is a general shift from simple skills to high-level cognitive skill sets.

Given this, one should be cautious about generalizing from the research on skill decay/retention, since the vast majority of the research involves studies of single and relatively simple skills, the prototypical ones being simple motor tasks, tracking tasks, and vocabulary learning tasks.

Psychological explanations of memory and skill loss invoke concepts such as decay and interference, memory trace strength, retrieval blockage, and "dilution" of memories (see Landsdale & Baguley, 2008; Wixted, 2004). All the models attempt to explain how there is a proportional decline in memory loss as a function of the age of the memory (i.e., Jost's Law that of two memory traces of equal strength at a given time, the younger trace will decay more rapidly than will the older).

Almost all the research is academic, and looks at tasks involving memory of simple materials such as words word pairs, or sentence or pictures. This leaves a rather large conceptual gap between this research base and issues of retention of knowledge and skill necessary for the conduct of complex jobs.

2.5.2 General Findings about Decay and Decay Rates

Retention of skill can be evaluated in a number of ways. One is to compare performance at the end of a training period with performance after a retention interval during which there was no practice. This evaluation reflects performance loss. Another method is to look at the obverse, using the "method of savings": it usually takes fewer trials or less time to re-achieve some criterion level of performance than it took originally to achieve it. This is taken to reflect the strength of the original learning.

The Extent of Decay

Rubin and Wenzel (1996) analyzed data from over 200 published studies that demonstrated the decay of long-term memory. With the exception of autobiographical memory (which has certain unique aspects), other materials show the typical decay curve in which most forgetting occurs within some brief span immediately after the original learning, typically within the first year up to about three years. (While most of the data sets were from studies of declarative memory, not all were. For instance, one study was of the memory of infants who had learned to kick at the sight of a crib mobile.)

Arthur, et al. (1998) reviewed the literature on skill decay, incorporating summary conclusions from a number of earlier review articles.

> The effect of progressive knowledge or skill deterioration when knowledge and skills are not used or exercised for extended periods of time is a fairly robust phenomenon. Although the vast majority of the literature consists of laboratory studies, in applied settings, this is related to infrequent opportunities to practice or

perform acquired skills (p. 59).

In general, the relation between skill retention and the length of the non-practice or nonuse interval is negative. Arthur, et al., (1998) derived a broad generalization: After a year of non-use or non-practice, the average person is performing at less than 92% of their performance level before the beginning of the non-practice interval.

The Shape of the Decay Curve

Studies of loss of knowledge that was acquired in academic courses consistently show that considerable forgetting typically occurs within the first few years following instruction (e.g., Bacon & Stewart, 2006; Semb & Ellis, 1994). This same general finding of initial rapid forgetting followed by negatively-accelerated forgetting has obtained in some studies of motor skill learning as well as cognitive learning, although motor skill generally shows less decay than cognitive learning (Arthur, et al., 1993).

The *rate of decay* does not depend on the degree of learning—that is, although the amount of original learning may vary, the rate of forgetting is similar. In an experiment for the military, Schendel and Hagman (1991) found that the rate of decay did not differ even though initial performance for high and low ability soldiers differed (see also Wisher, 1999).

Figure 2.1 shows bombing accuracy data reported from an actual training environment for fighter pilots coming off of 14 hours of training at Fallon Naval Air Station. This figure can be taken as representative of learning/forgetting curves, showing substantial levels of decline after only several weeks.
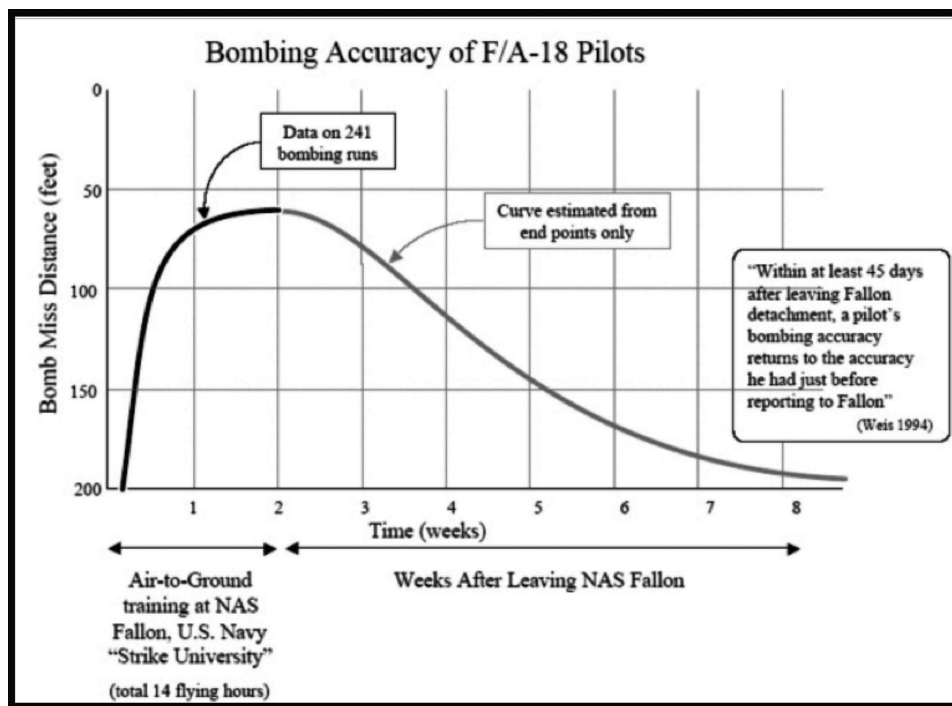
Figure 2.1. A performance decay (or "forgetting") curve.

The "decay" component of such performance curves is idealized in Figure 2.2
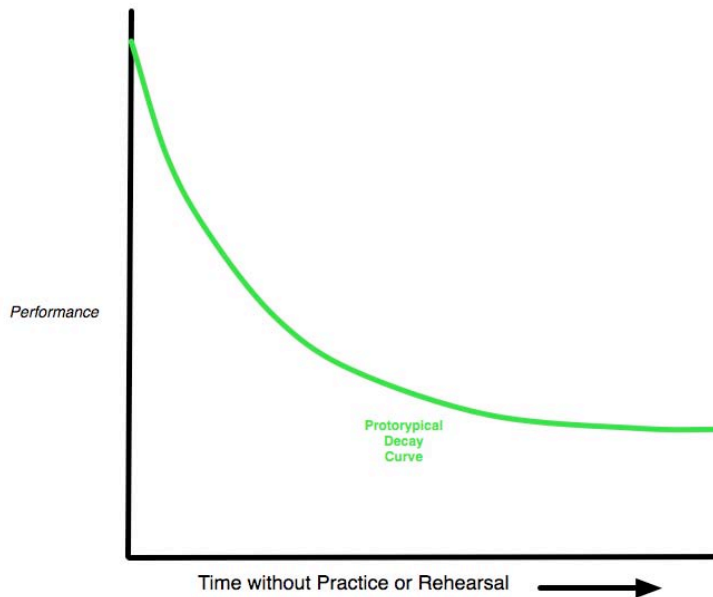
Figure 2.2. An Idealized performance decay curve.

Harry Bahrick and his colleagues conducted a classic series of studies on long-term retention/decay for mathematics and for Spanish learned in high school, on the part of literally thousands of people, tracking retention in some cases out as long as 50 years (Bahrick, 1979, 1983, 1984; Bahrick, Bahrick, & Wittlinger, 1975; Bahrick & Phelps, 1987). These studies found rapid and significant levels of forgetting in the few years after students had taken a one-year course in Spanish. Forgetting then levels off, with some knowledge being remembered after long periods of nonuse. According to Bahrick, successive relearning is essential for the retention in the memory "permastore" (1984). (In the case of memory for a second language, this would no doubt entail use, and not just relearning.)

Research consistently finds that the performance decline is rapid just following the training, but that the rate of decline decreases (i.e., negatively accelerated) (Arthur et al, 1998; Driskell et al. 1992; Wixted & Ebbesen, 1991; see also Lance et al., 1998). Figure 2.2 illustrates this concept. During training, proficiency increases to some level but decreases over time after training. This can be modeled using a number of two-parameter equations, such as Anderson and Schooler's (1991) power law of forgetting based on assumptions about the decay of memories (i.e., the strength of a given memory is a log function of original memory strength and log time since learning) (see also Wixted & Ebbesen, 1997). Generally, forgetting curves suggest that humans lose nearly 50% of their memory for new material (in declarative knowledge learning tasks) within a day unless some form of review is engaged (see Wixted, 2004 for a discussion).

The literature on the rate of skill decay for cognitively-based tasks (i.e., problem solving rather than perceptual-motor skills) seems to suggest similar rates of decay. Wetzel et al. (1983) looked

at learning and retention for a perceptual-cognitive task (oceanographic analysis) and found 21% decrease in scores after a month (Wetzel, Konoske & Montague, 1983) and problem solving skills were shown to drop 16% after two months (Austin & Gilbert, 1973).

The Decay Curve in Military Jobs/Tasks

Numerous studies of retention in military domains have demonstrated decay. For instance, Wetzel, et al. (1983) followed 20 individuals who were receiving training in antisubmarine warfare, comparing performance during an acoustic analysis training course and performance after 25-days of "non-utilization," to determine what they had retained from the course after this period. Both pre and post conditions used two kinds of tests, multiple choice and performance measures. The learners' knowledge and skill were found to "degrade significantly."

The problem of skill decay among military personnel as a consequence of rotations or hiatus periods has been documented for some time (e.g., Wisher, et al., 1991) and not just in the U. S. Military (see Henik, et al., 2001).

Studies of the retention of soldier tasks have shown effects of degree of initial learning, active practice (practice on actual equipment rather than in the schoolhouse), and spaced practice (Stothard & Nicholson, 2001). In an extensive and well-controlled study, Kneer, et al. (1984) evaluated soldier retention of eight procedures in the repair of armored equipment. Their study confirmed the impact of the above variables. The procedural tasks that were examined varied in length, complexity, and amount of training/practice during actual operations. Performance was measured after training, then four weeks later, and in some cases up to 72 months after training. The results support other retention studies that show rapid decay after training, with fairly stable performance over longer periods of time.

Henik, et al (2001) examined skill decay on the part of tank gunners and missile aimers (about 80 of each) who had just been released from military service. Six and eighteen months later, their skill was tested in multiple scenarios, and their declarative memory was tested as well. Findings showed very small but statistically significant loss of declarative knowledge about the job (about a 5% drop), most of this occurring between 12 and 18 months. The findings also showed a more dramatic loss of skill (decreased average and increased variability in speed and accuracy).

Marmie and Healy (1995) studied the retention of skill at tank gunnery, a job requiring both discrete and continuous skills, both motor skills and cognitive skills. After 12 trainings sessions over four weeks, there were retention tests from one out to 22 months. The main finding was the typical decay curve, that is, rapid initial loss of skill.

Lance, et al. (1998) investigated skill decay for a number of U. S. Air Force enlisted specialties (including air traffic controller, ground equipment mechanic, radio operator, avionics, others.). An attempt was made to link decay to such variables as aptitude (data from personnel files), task difficulty (ratings data from the USAF task inventory), initial skill level (gauged on the basis of participant experience), and performance level in "last time performed" reports. The results showed the expected relation of performance to retention interval (and fairly high retention for the less complex tasks). This and other studies permit the extension of the general skill/memory decay finding from academic research (i.e., of simple perceptual-motor tasks and declarative memory tasks) to military jobs.

However the relation of retention interval to amount of decay was not strong since other moderator variables were at work. With regard to those moderator variables, there were many

interactions and no strong correlations. As in all research in this area, there are many complicating considerations of experimental design and control for potential confounds. For example, studies need to control for initial over-learning. As another example, during a hiatus an individual may not have conducted their primary tasks but might conduct similar ones. "Additional unmeasured performance determinants (e.g., motivation, prior job knowledge) may have overshadowed the effects of extended retention intervals on task performance" (p. 118).

Factors that Influence Decay

Major factors that influence the decay or retention of trained skills over extended periods of nonuse are (a) the length of the retention interval, (b) the degree of overlearning, (c) certain task characteristics (e.g., closed-looped vs. open-looped tasks, physical vs. cognitive tasks), (d) methods of testing for original learning and retention, (e) conditions of retrieval, (f) instructional strategies or training methods, and (g) individual differences.

Arthur, et al (1998) drew a valuable distinction between methodological and task factors. Methodological factors are those that can be modified in the training or learning context to reduce skill loss (e.g., degree of over-learning, conditions of retrieval).

Task Factors

Task factors are inherent characteristics of the task and are typically not amenable to modification (e.g., motor versus cognitive tasks).

Schendel, Shields, and Katz (1978) reviewed the research on retention of motor skills and concluded that the most important determiner of retention is the level of performance achieved prior to hiatus. Arthur, et al., conclude that the single most important of these variables appears to be the amount or degree of over-learning as a consequence of training beyond that required for initial proficiency. Over-learning is the deliberate practice beyond the point of having reached some criterion level of performance (Driskell, et al., 2992). The degree of over-leaning can be scaled in terms of the number of practice trials after achieving criterion to the number taken to achieve criterion (expressed as a percent).

Explanations include the basic law of frequency of association, the possibility that over-learning prevents decay, the possibility that additional practice brings with it additional feedback, and the possibility that over-learning enhances trainee confidence.

It has generally been found that spaced practice during training results subsequently in better retention than massed practice, especially with a long retention interval, or delay between the end of learning and the beginning of testing. In fact, optimal performance at test seems to result when the interval between practice trials is approximately equal in length to the retention interval. This conclusion seems to hold even when practice is distributed across sessions rather than across trials within a session (Healy, 2007). Bahrick and Phelps (1987) showed that when Spanish vocabulary was learned over a longer time period (six to nine study sessions over 30 days vs. six to nine sessions back-to-back), the retention of this material 8 years later was increased. Repeated exposures lead to greater learning (Bacon & Stewart, 2006; Halpern & Hakel, 2003), and when those exposures are spread over time they appear to be even more effective.

This finding has a direct implication for retraining following hiatus. Many ideas about skill retention during hiatus involve practice experiences that would inevitably be massed in the sense of concentrated at particular times within the practitioner's primary work schedule. The literature on distributed practice would suggest that training during hiatus be distributed.

The effect of over-learning can be hidden by the effect of mental rehearsal or imaginary practice during the retention interval (Farr, 1987). According to the notion of encoding specificity (Healy, 2007; Tulving, 1983) and the similar notion of "procedural reinstatement" (Healy, et al., 1992), performance following a retention interval will be better if the retention task (the way information is encoded) is similar to the acquisition task (the cues used to stimulate a memory). Thus, skill retention appears to be greater if the retention measurement is conducted in a context similar to that of the original learning, e.g., the similarity of the training device to the actual job equipment (Farr, 1987; Schendel, Shields, & Katz (1978). In a study of tank gunner skills Marmie and Healy (1995) found that if the training is sufficient and if the post-retention task itself relies on cues that are present during training, then retention of skills can significant for up to 22 months.

The type of task can determine the effect of over-learning on skill retention (perceptual-motor skill versus cognitive task) (Ryan & Simons, 1981). This is discussed in more detail below, in the section on "differential decay."

Methodological Factors

Different retention measures can yield different degrees of apparent retention (Farr, 1987). Many choices have to be made in designing experiments, and one consequence is that different studies use different criteria (Farr, 1987). "Proficiency" or "mastery" at a skill has been defined as "one errorless trial." Learning continues beyond that point that accuracy is perfect, and, more importantly, "accuracy asymptotes rapidly in many tasks, leading to a potentially false conclusion that the material has been mastered… [and] because learning continues past error-free trials, overlearning may really just be a higher level of skill acquisition" (Arthur, et al., 1998; p. 91; see also Regian & Schneider, 1990).

The primary individual difference that has been studied is intellectual ability. In general, low ability learners and high ability learners tend to learn different things, learn different things differently, and show different patterns of decay. Lower ability learners forget larger portions of abstract, theoretical material than do higher ability individuals. Higher ability individuals retain more knowledge or skill over periods of nonuse than lower ability individuals, but this can be because higher ability trainees acquire more knowledge or skill during training (Farr, 1987).

2.5.3 Retention of Piloting Skills

Following a hiatus it is necessary for fighter pilots to reacquire a feel for high-performance flight, even though pilots we interviewed say things like *Flying is like riding a bike.* Our focus in this Report is on the retention of the broader spectrum of flight skills, including mission-relevant and tactical skills. Research on this topic constitutes an extensive literature. Prophet (1977) provided an annotated bibliography of 120 articles. In this Report, we review selected studies that are representative of the main and consistent findings.

Childs, et al. (1983) investigated retention of flight skills in civilian pilots at intervals of 8, 16, and 24 months after receiving certification from a course of training. Significant skill loss was found and manifested the forgetting curve described in the psychology literature. Groups who had flying experience during the retention interval fared better than those with none, but they still showed significant decrement. Skills that require appreciable coordination between cognitive skills and "control skills" were among those most substantially degraded. Writing in 1983,

Childs et al. proposed that are training should include "cognitive training" (especially for cognitive cues), and "full mission simulation."

Wright (1973) examined retention of flying skills after periods of non-flying and minimal flying. All of the measures of flying proficiency were estimates produced by the subjects themselves, including not only estimates of their ability at the time of measure (after the period non-use) but also retrospectively (e.g., back to when they were first certified after training). The findings show that pilot judgments are consistent with findings about performance decline. Pilots know that most skill loss occurs early, within the first year, and that skill loss slows marginally after that.

To relativize the above findings, which might be regarded as typical, Prophet (1977) culled the available literature for data on "basic flight skills" after long retention intervals. He found evidence that basic flying skills are retained fairly well for extended periods of non-use. Nevertheless, Prophet (like Childs, et al. and others) proposed that proficiency/retraining demands can be met by simulators and other training devices. However, Prophet also asserted that that not enough was known (then) about the retention of "higher level tactical skills" or strategies. In concert with Prophet's findings (1977), Wright (1973) found that instrument flying skills were shown to deteriorate more substantially than basic flying skills (visual flight).

Refresher Training for F-16 Fighter Pilots

There are no "tests of expertise" for fighter pilots. As an experienced fighter pilot and fighter pilot trainer remarked, *"Highly proficient pilots pass their qualifications with distinction. They can think, decide, and act rapidly. They can recognize patterns that others cannot. They can act by intuition. They feel good about their strengths and are comfortable with their weaknesses."* Fighter pilots are also considered expert if they have been through the Weapons School.

The refresher course can last from one to six months depending on how long the pilot has been away from the weapon system (or whether they are moving to a new weapon system). According to an experienced fighter pilot trainer in the F-18 Transition Course (Healy, 2008), fighter pilots show different attitudes upon entry to the refresher course: *"I have to catch up"* versus *"This will be easy."* The former tend to be more expert, and typically are themselves experienced trainers. "[They are] voracious readers and question askers; they feel passion about the plan and the mission. They recognize their own limitations and lack of currency. They recognize that they aren't going to get smarter in their new job" (Healy, 2008).

The fighter pilots who express the "this will be easy" attitude are typically ones who typically have mid-level experience (i.e., as a light lead but not as a fighter pilot trainer). They express an attitude of wanting to "survive the program." Healy (2008) argues that these pilots are more dangerous because they approach the refresher training on the assumption that they will "get smart" once they get to their new job. "They don't know what they don't know" (Healy, 2008).

Healy also observed that fighter pilots who use the simulator a lot tend to be more passionate, and likely want to be weapons officers.

Trainer experience in the F-16 Refresher Training is that no one comes back after a hiatus of any duration (more than a few months) at greater than 80% proficiency. For long hiatus, proficiency upon return is estimated at 40-30%.

As described by Healy (2008), the progression of training goes from:

(Track 1) Two (friendlies) on one (adversary) start miles apart and converge. Track 1 is for the least experienced individuals (out of cockpit for at least 8 years). There are 242 academic modules, 38 sorties, 20 simulation sorties.

(Track 2) Two against two. Track 2 is for individuals out 3-8 years. There are 152 academic modules, 17 sorties, 14 simulator sorties.

(Track 3) Four against four, flying low and with bombs. Track 3 is for individuals out less than 3 years. 35 training days include 165 academic modules; 11 sorties, 13 simulator sorties.

(Track 4) Capstone of 1 against 4. The fighter pilot's job is to not die and to put effective weapons against a target.

Where the fighter pilot starts in the refresher training depends on the length of their hiatus. For instance, individuals whose hiatus was only a few months would start at step 3. Also, there would be fewer sorties with more stuff packed into each sortie.

After the Step 4 capstone, the (re)trainee goes into the operational Air Force, but training continues there, using the same progression (stages 1, 2, 3) but adapted to the local adversary and nature of the deployment. The local check out can be 10-14 sorties, one each of different mission sets. The fighter pilot learns the local flying environment, the diversion routes, and the instrument approaches. The weapons on an aircraft change its flight characteristics, the g-force stresses on weapon mountings, etc.

The dynamic complexity of the fighter pilot's job seems nearly overwhelming to the outsider (Healy, 2008):

- There are different versions of the F-16, each with its own unique engines, software, etc.

- On any one flight the aircraft will be configured for one of many possible mission types (reconnaissance, strike, air-to-air, etc.). *"Each mission is the soup of the day."*

- There are always new tactics to learn, and new terms for planning and communication. There are five major tactics manuals and these are rewritten every 2 years.

- There are new challenges of joint and coalition operations (e.g., the confusion over whether "abort" means a plane moves off versus entire mission is called off.)

- There are challenges to memory and multitasking, After a mission debrief, the pilot plans the next day's mission. After a training sortie and debrief, trainees will study for a training sortie they will do one or two weeks in the future. *"This is a constant leapfrog."*

- The aircraft are always being changed. Manuals are rewritten regularly. The plane's software upgrades every two years. There are upgrades to all the avionics and hardware.

All this being said, the technology for human-system integration is improving. *"New helmet means we can use the buttons to do more than one thing. Press, press and hold, press twice. New data display tells what other aircraft are doing."*

Related to the theme that deployment itself contributes to the achievement of proficiency, in the fighter pilot domain a great deal of learning is accomplished and shared in the debriefings. A debriefing and group discussion can last longer than the mission. If a sortie went bad, a debriefing can last five hours.

Although all debriefings have unique aspects, there is a schema. The sortie Lead stands up, asks questions that can only be answered yes or no. The Lead might already know what the trainee slipped up. "Were you too fast or slow?" Questions are also about tactical administration. "Did we follow the safety rules?" The trainee will recreate the mission on whiteboard, using video records and instrumentation data. Error points will be highlighted. A main purpose of the debrief is to identify root causes (e.g., for why someone "died" (e.g., the radar was not looking in the right part of the sky). It takes time to build an accurate picture integrating visual observations, radar data, communications data, etc. Then the Lead will provide an instructional fix based on the learning points. This involves linking the debrief results with what is programmed for the next simulator sortie.

The F-16 training program also includes training of the trainers, having its own syllabus. Training sortie debriefs include de-brief of the trainers with regard to the training itself.

Interviews with Fighter Pilots concerning Hiatus Experiences, Effects and Retraining

In May 2009 interviews were conducted with ten current and retired USAF pilots. Four were retired F016 fighter pilots who had achieved the rank of Lieutenant Colonel. Another had served in Special Operations as a helicopter pilot in border patrol and had achieved the rank of Colonel. Another had been primarily a B-52 pilot then a B-2 navigator. Another was primarily a UAV sensor operator. Two had experience flying AWACS. One had additional experience flying Joint Stars. Specific career data available on three of the interviewees specified the range of flight hours logged between approximately 1600 and 2340. All interviewees had experienced rotation out to a staff job, which for three interviewees involved jobs close to aviation (e.g., Flight Instructor, Ground Controller, AOC duty) or relatively distanced from it (e.g., Course Director in Military Studies, NATO C2, RAF liaison), followed by reentry into a position which might have been more, or less related to their original flying assignments (e.g., weapons school instructor). The focus of the interviews was to investigate these experiences, especially regarding decline of skills while on staff rotation and recovery of skill upon rotating out of the staff position, back to a more front-line position.

There was general agreement that skills do decline during staff rotations. One interviewee asserted that "*Most of my deployments I have never seen skill decay. Even holding 12 hours over Iraq, even in a complex sorties, and not doing air-to-air skills, you do not get skill decay.*" But then he added "*Two-three weeks do some fancy flying, and you are ready quickly.*"

There was general agreement that loss of basic flying skills is less an issue than loss of tactical skills, and that practice during hiatus at flying a simulator would by itself not be sufficient: "*Good sims at the staff job aren't enough. You need to have current guys to fly with*". On the other hand, there was also a consensus that it might not take much in the way of maintenance/refresher training to maintain tactical skill:

> *"Two sorties per month, I could probably keep him tactically. Even flying in the back seat would not hurt. Monthly basis is needed to keep an edge... A reserve guy said, we have all these reservists flying 5-8 sorties a month, keeps them able to take off and land and fly. If I saved those sorties and put them in sims to do tactical things, could*

> *have a 5-10 year shelf life of this guy, give a one month transition and they are ready to go. Keep them "almost ready" and save a ton of sorties. Unless you get 5-8 sorties per month, they can be dangerous. So just let them do sims and keep up on tactical since you need to do the retraining for piloting anyway."*

While decay might be an issue for certain skills, the specifics vary with a number of factors. These include the following.

1) The experience and skill of the pilot before rotation. There was a consensus that the better the pilot was during active flying, the easier was the reentry after the hiatus staff position. However, this effect was moderated by a general decrease in the number of flying hours required before a pilot could rotate out, from about 1000 hours to 750. There was a consensus that rotating back was becoming more of a challenge as pilots had less pre-rotation experience. The importance of skill was noted in comments such as *"It's a complete bell curve," "Some guys jump right back in, some guys never get it back"* and *"An ace before, an ace afterwards." "A middle of the road pilot is still a middle of the road pilot."* It is consistent with the expertise and retention literature (e.g., in studies of overlearning) in general, that the greater the level of skill development before a hiatus the higher the level of skill at the end of the hiatus (greater retention) and the faster the skill will recover.

2) The nature of the staff position in relation to the prior and subsequent ones. It is clear that the more the staff position resembles or is related to the prior positions, the less will be the skill decline (or perhaps interference). However, it appears that the needs of staffing are acute enough that such targeted assignment is not often feasible. To the extent possible, it would be desirable to coordinate staff positions with prior and subsequent duties, so that, rather than interfering skill retention experiences could be complementary—providing a different, useful perspective on the job.

3) The opportunities for practice and refresher during the staff position. There was a consensus that practice or refresher activities during the staffing rotation would be beneficial for maintaining skills, but that duties and responsibilities typically make it difficult to impossible to add refresher training in simulations or in flight. No specification was offered in terms of simulator hours but it was acknowledged that skill maintenance activities are hard to squeeze into a hectic pace of duties. It was noted that different kinds of activities might be preferable for different kinds of skills, e.g., computer driven exercises for keeping current on checklists, procedures, and simulations of various kinds and contacts with active flyers (e.g., through blogs) for keeping up with tactics and equipment advances.

4) The nature of the transition (TX) course back to active flying duty. There are structured reentry experiences for those rotating out of a staffing position back to more front-line services, including flying (Air Force Instruction 11-202 and its modifications; see U.S. Air Force, 2005). These experiences are, in some cases, tailored to the prior experience of the person, the length of time away from flying, and the new job to be assumed. It is important to note that is often the case that the new position does not involve active flying of the same sort as before rotation. The assignment might, for example, be more supervisory. After any refresher or transition training, the nature of the post-rotation assignment will itself continue to affect the level of degradation of

skill and recovery. A key factor then is the degree to which pre-rotation activities and those during hiatus are consistent with the demands of the new job post hiatus.

An argument might be made that the Air Force practices work against the acquisition and retention of expertise. As one interviewee said,

> "*When the Air Force finds good people, they have them do something else, since they are the future. The people left behind are average, but they get more experience. By the time they make Major, they are half the people. The Canadians, British, Dutch, they do not have the up-or-out system we do. This allows mentoring. Some captain teaching others, a job he has done for decades.*"

2.5.4 Differential Decay

Not all forms of skill (reasoning skill, perceptual-motor skill, etc.) decay at the same rate or in the same ways.

In an Army study, Johnson and Cosby (1985) developed a prediction instrument based on input from experienced trainers, who decide when a soldier needs training and then plan the training. The predictive instrument requires the soldier trainer to rate the task in terms of complexity (steps, time limit, mental requirements). From the ratings an overall score is derived for each task, and is used to predict decay rate for that task. As one would surmise, the prediction of decay rates based on judgments of experts would be useful in predicting decay for tasks that have no accompanying memory aids, that are complex procedurally, that require significant amounts of knowledge, are hard to remember, and also have significant motor skill requirements—tasks that are likely to show faster decay.

In contrast, a classic finding in the motor skills literature is that performance after learning simple motor skills (e.g., accuracy at the pursuit rotor) drops by only about 25 percent after a year (Bell, 1950). Fleishman and Parker (1962) studied performance at a target-tracking task (similar to the pursuit rotor but also analogous to radar tracking) up to a high level of proficiency (integrated error) and then tested performance after two years of nonuse, finding very little loss of skill (i.e., return to highest proficiency after only about five trials). The primary determinant of performance following non-use is the level of proficiency achieved up to the point that the retention interval begins

In the classic studies of forgetting by Harry Bahrick and his colleagues, they showed the classic decay curve for second language and mathematics learned in high school, but that decay finding did not obtain for memory of names and faces, over intervals that ranged up to 57 years (Bahrick, Bahrick, & Wittlinger, 1975).

A series of reports by Alice F. Healy and her colleagues to the Army Research Institute for Social and Behavioral Sciences detailed the many task variables that influence the decay of skill learning during periods of nonuse. Some studies examined skill retention for skills having military analogs, others used tasks representative of the educational (college) context: target detection tasks; circuit design, algebra problem solving, data entry tasks, memory for class

schedules, vocabulary learning. Later studies in the ARI project looked at tank gunner skills, more code learning, and instrument panel scanning.

The findings were varied and mixed both with regard to the effects of the key variables and individual differences. While performance following hiatus showed a decline and was linked most strongly to the level of performance achieved just prior to the hiatus, in some studies and for some participants, performance following a hiatus showed improvement, not decay. Skill at multiplying two large numbers reached a point of near-automaticity after extensive practice and showed almost no decay after a seven-month hiatus. The studies of vocabulary learning utilized the mnemonic technique called the "keyword" method, which relies on mental imagery and is know to be robust to memory decay (see Hoffman & Senter, 1979). A number of studies conducted in this ARI project found surprising levels of knowledge and skill retention (the target detection, multiplication and data retention tasks), supporting Bahrick's notion of the "permastore."

In the Henik, et al (2001) study of retention of gunnery knowledge and skill, a "refresher day" boosted performance on the declarative memory test back to near the original level, but had no impact on performance at the scenarios.

We know that perceptual-motor skills can be highly specific to task and context. Healy, et al., (2003) cite a study showing that performance at using a computer mouse is significantly disrupted by changing the relation between mouse movements and cursor movements (an example of negative transfer or interference). One is tempted to generalize that factual ("declarative") information shows poor retention but robust transfer whereas procedural knowledge (skill) shows good retention but limited transfer. Although knowledge can be forgotten very rapidly, learned skills are usually well retained across periods of disuse. Healy gives the example of learning how to use a hula-hoop as a child and able to use a hoop again well as an adult, even if there was no intervening practice with the hoop since childhood.

The differential retention of procedural skills (perceptual-motor) versus declarative knowledge is noted in all of the reviews, but the inconsistencies in the findings make generalization tentative. One possibility is that simple motor skills are more memorable precisely because of their simplicity, and that even the more complex procedural skills that have been studied are ones involving task procedures can be put to rote memory (Healy, et al., 1992).

Within the general "skills" class, it has also been noted that there is differential retention of skills continuous ("open-loop") versus relative differential decay of skills that are discrete ("closed-loop"). For instance, after training at an aircraft simulator people will tend to forget checklist procedures but retain skill at the dynamic continuous task of actually flying the plane (Mengelkoch, Adams, & Gainer, 1971). Some studies find that performance at closed-loop tasks seems to decay faster but a meta-analysis failed to affirm this generalization (Arthur, 1998).

As the above discussion suggests, generalizations about decay/retention are difficult to formulate. One cannot conclude that perceptual motor skill will invariable be retained better than declarative knowledge, for example. Based on their studies, Healy et al. generalize that occasional or periodic practice or refresher work during hiatus can help maintain performance. There is some evidence, not surprising, that the refresher practice can be helpful if presented just prior to the critical test of retention. In other words, refresher practice does might not have to be distributed across a hiatus (Healy, et al., 1995). They generalize that performance evaluation in

the context of evaluating decay needs to be conducted in a way that reinstates the original learning procedures and the context used during the training.

2.5.5 Generalizations About Decay/Retention

<u>Main Generalizations</u>

Two main generalizations can be asserted.

(1). The best predictor of skill retention following a hiatus is the level of performance achieved (including over-learning) prior to the hiatus. This finding applies generally, including to military tasks (see Hagman & Rose, 1983).

(2). The variable having the largest impact on performance after a retention interval is the similarity of the conditions of testing to those of the training.

> The results of this study suggest that the similarity of the training (acquisition) and work (retention) environments plays a major role in the retention of skills and knowledge over periods of nonuse… to enhance retention, trainers should try to ensure the functional similarity of both the training device (acquisition) and actual job equipment (retention) and the environment in which both are performed (Arthur, et al., 1998, p.86).

> This result is interesting because conditions-of-retrieval is directly related to the issue of transfer of training. Transfer of training is the generalization of trained performance, in a given task, from the training environment to the work environment and is one of the key criteria for evaluating the effectiveness of any formal training program (Arthur, et al., 1998, p.86; see also Kirkpatrick, 1987; Schendel, Shields, & Katz, 1978).

The very concepts of encoding specificity and context specificity tend to play against notions of transfer.

<u>Inconsistencies and Complications</u>

The study of retention is complicated by a potential disconnect between the skills that are trained and the skills that are actually exercised in operational performance. For instance, in their study of soldier retention of equipment maintenance tasks, Kneer, et al. (1984) noted a disconnect between relation-the-job ways of conducting tasks and the way tasks are "taught in school, " which might entail negative transfer. Rose, et al (1985) presented a method for predicting how fast various skills will decay and hence need retraining (see also Johnson & Cosby, 1985). The method queries learners, for example: "Does the task involve a job or memory aid?" The questions refer to how it is trained and tested, rather than how it might actually be done (e.g., with short-cuts, embellishments, work-arounds). These kinds of instruments seem to test for retention of training material and methods, rather than on-job capability.

Although the decay function usually obtains in the research, for both movement skills and cognitive tasks (Arthur, et al., 1998), some studies show good levels of retention of declarative knowledge in the months and years following learning. A study by Semb and Ellis, (1992) on

college student memory for material learned in a developmental psychology course (85%-75% retention after four months and 80%-70% retention after 11 months). Adding to this, Semb, et al., (1993; see also Gaynor and Wolking, 1974) found that student tutors retained more after 4 months than the students they tutored. This suggests that tutoring has its own learning benefits.

Even the phenomenon of over-learning is not immune from qualification. Rohrer, et al. (2005) demonstrated the effect of over-learning (additional learning trials) for students who learned geology facts and word definitions, and were tested one and nine weeks later. While the over-learners showed better recall at week one, by week nine the advantage had been lost. As Arthur, et al. (1998) pointed out, "[A]ccuracy asymptotes rapidly in many tasks, leading to a potentially false conclusion that the material has been mastered… [and] because learning continues past error-free trials, overlearning may really just be a higher level of skill acquisition" (p.91; see also Regian & Schneider, 1990).

Task complexity does not always have a pronounced effect. In an analysis of skill decay in realistic work settings, Lance et al. (1998) found a small effect of task complexity but in a review of readiness for duty of reserve recruits, Wisher (1999) reported that task complexity (measured by number of task steps) did impact the degree of retention over longer periods of time.

> Differences in inherent organization and content structure, prior student knowledge and experience, task requirements/demands, and other related variables may contribute to these discrepant findings (Semb, et al., 2003, p. 315; see also Arthur, et al., 1998).

Complexities of experimental design and measurement issues (see Arthur, et al., 1998; Semb, et al, 1993; Bacon & Stewart, 2006) make it difficult to form generalizations that might be carried over to the consideration of accelerated learning.

Arthur, et al. (1998) point out that retention of skill involves more than just task performance, since other forms of evaluation are possible (e.g., worker contribution to organizational goals), and furthermore that other factors can influence performance in the operational context. Affect and motivation are not tapped in studies that look exclusively on the retention and decay of knowledge. This is an important consideration since high levels of motivation, that is, intrinsic motivation to work on hard problems, is a defining feature of what it means for an individual to achieve the highest levels of proficiency.

A seemingly overwhelming number of factors are in play in the training-performance context. Classes of factors are task factors (e.g., difficulty, representativeness), practice factors (e.g., massed versus distributed practice, degree of overlearning), acquisition tasks (motor skill versus cognitive, procedures versus closed loop tasks), test tasks (recall, recognition), trainee characteristics (motivation, intelligence), feedback type and timing, and retention interval.

In research on retention/decay, participants are often not tested beforehand to assess prior knowledge. Previous experience or knowledge can facilitate long-term skill retention even though individuals with and without prior experience might exhibit the same level of skill immediately after training (Bahrick, 1979). It is possible therefore that criterion performance at the end of training is not appropriate for use as a predictor of long-term retention.

Since the shape of the decay function is so dependent on multiple interacting variables (Naylor & Briggs, 1961) training for any particular job or task must be based on a task or job-specific knowledge of the course of forgetting in order to determine the best plan for maintenance

training or re-training (Arthur, et al., 1998).

The experimental psychology of learning (retention/decay) focuses on the learning and retention of tasks (e.g., perceptual-motor skills) or sets of content (e.g., Spanish learned in high school). Arthur, et al. note that the study of skill decay/retention for tasks that involve perceptual learning and perceptual skill (e.g., pattern perception) has not been studied much. This gap in the research base for training psychology is significant since, as work in the area of Expertise Studies has shown, many jobs where proficiency is required and expertise is desired are jobs that involve significant perceptual learning and perceptual skills (e.g., radiology) (Klein & Hoffman, 1992).

In significant domains of professional practice, including in the military, jobs are defined by multiple "tasks" and multiple kinds of "tasks." And indeed we put the word "tasks" in scare quotes because professional jobs do not consist solely of the performance of tasks at all, in the sense of a stepwise procedure for linking means to ends. In actuality, cognitive work involves the context-sensitive, knowledge-driven choice among activities. Professional domains involve some tasks, and often it can appear as if the practitioner is conducting a task, but this will be when the situation is routine and the goal is well-defined.

2.6 Team Training

In most controlled studies, experimenters have distinct groups of participants who are often called novices and experts. However, in a real work environment, individuals at various levels of experience and proficiency are always working together. Workers at all proficiency levels can be accountable for one another's actions, they can give instructions as tasks are carried out, they can devise coordinated solutions that mix knowledge and skill contributions, and they are often bound in social and work role hierarchies (Lajoie, 2003).

The generalizability of findings from laboratory studies or from research using non-military teams may be an open question. However, a recent meta-analysis on "team training" (Delise, et al., 2010) found evidence that there were no differences between civilian and military teams, nor were there differences across research settings (i.e., lab or field). Further, there were no differences between ad hoc and intact teams. Because both civilian and ad hoc teams in the studies comprising the meta-analysis were likely college students, this suggests that findings from this literature may generalize to studies concerning how to accelerate learning in teams. Importantly, with regard to measures related to transfer, although there were some differences in cognitive outcomes based upon the setting of the evaluation (lab or field tests), there were none for task or teamwork skills. They note that this suggests that:

> [T]raining is similarly effective in both proximal and distal application situations, except with cognitive outcomes. Most critical to the present purposes, analyses indicated that training had large positive effects on cognitive outcomes for training and transfer outcomes, but the effects were larger for transfer outcomes than for training outcomes (Delise, et al., 2010, p. 70).

2.6.1 Complex Cognitive Work *is* Teamwork

This Report has emphasized proficiency in domains of "complex cognitive work." Such domains are also called "sociotechnical systems" in recognition of the fact that the work is conducted by collaborations of people and technologies (see Hoffman & Militello, 2009).

A study of expert software teams by Sonnentag (2000) showed that experienced problem solvers place a high value on cooperation and engage in more work-related communication. The problem solving process in many complex domains relates clearly and directly to team cognition research in areas such as software development, system administration, and design teams – these range from somewhat homogeneous teams, such as in software development, to often heterogeneous teams such as in systems administration, but these teams are all created to develop, manage, and maintain some complex technological product or system.

Teamwork is necessary for many aspects of the problem solving process, and team members need to be trained accordingly. First there is a need to recognize that a problem has occurred followed by the need to define and represent that problem, culminating in discussions about generation and testing of particular solutions. Problem recognition can be an individual or a team task. Critical to subsequent problem solving processes is information sharing, in that the heterogeneous nature of the team's knowledge and/or the particular roles of the team members require efficient sharing of data based on each team member's understanding of the needs of the other team members. The distributed nature of the work sometimes means that information from differing sources needs to be integrated, and this is often a team task rather than an individual task.

Many collaborative tasks consist of a dynamic social-cognitive process requiring diagnostic interrogation of some system and diagnostic questioning from an often times ad-hoc team. Haber (2005) refers to this as "group sense making."

> A problem existed due to interactions between the components of a very complicated system, and the experts on the different components needed to work together to understand the cause and find a solution. The overall strategy was a cycle of shared observations of the system in question, developing hypotheses as individuals, small groups, or the group as a whole, and implementing changes to attempt a fix (p. 3).

Maglio, et al. (2003) similarly discuss computer systems administration from a perspective of complex problem solving, also noting the social-cognitive nature of the collaboration. They describe a requirement for developing common ground and the coordination of attention across a number of team members, ranging from engineers engaged in trouble-shooting, technical support personnel, and software application developers.

A crucial part of this process is the emphasis on cooperation strategies that are utilized in system administration. The work places high cognitive demands on practitioners.

> As system administrators troubleshoot systems, making sense of millions of log entries by controlling thousands of configuration settings, and performing tasks that take hundreds of steps. The work also places high social demands on practitioners—as systems administrators need organizational and interpersonal skills to

coordinate tasks and collaborate effectively with others (Barret, et al 2004).

Related to this, Sonnentag and Lange (2002) found that among engineering and software development teams, a general knowledge of cooperation strategies, that is, what to do in situations requiring cooperative behavior, is related to better performance. Cooperation is more valued by the experts than by the moderate-level performers. Experts engage in higher amounts of work related communication, helped their coworkers, and sought out feedback from coworkers (Sonnentag, 2000). Another finding is that teamwork improves following training in which teams are given prompt meaningful feedback about how they coordinate (Salas, Nichols, and Driskell, 2007).

The team leader can play a critical role in complex problem solving teams–enabling (or obstructing) information sharing and coordination. The team structure and conflicting team member goals and roles can sometimes impede problem solving (Haber, 2005).

> We refer to this collaboration pattern as "Seven People, One Command Line," as various people participated in troubleshooting, but only George had access to the system. His manager wanted to know when the problem would be fixed and whether others should be redirected to help him complete the task on time. The support person wanted to resolve the problem ticket and end the call as quickly as possible. His colleague wanted to help within the limitations imposed by his own responsibilities. The system architect wanted to know if there was any problem in the overall design without being mired in the details. Other specialists waited for instructions to manipulate the subsystems they were responsible for. The problem was eventually found to be a network port misconfiguration. George misunderstood the meaning of a certain configuration parameter for the new web server. George's misunderstanding affected the remote collaborators significantly throughout the troubleshooting session (p. 4).

Finally, the team leader can play an important role in complex problem solving teams – enabling [or obstructing] information sharing and coordination. For example, from the standpoint of teamwork and problem solving, Haber (2005) noted how the team structure and conflicting team member goals and roles can sometimes impede problem solving.

2.6.2 Coordination

Nancy Cooke and her colleagues have conducted a great deal of research on team coordination in command-and-control environments, especially focused on the development of team coordination skills (Cooke, et al., 2007). The authors characterize team command-and-control tasks as challenging because they are: 1) defined by unanticipated situations, 2) often involve ad-hoc team structure, 3) team members may not be familiar with each other, 4) little team training occurs over some time periods (i.e., stretches of time without further training). The researchers have primarily addressed the third and fourth issues within the context of Unmanned Air Vehicle (UAV) command-and-control. This effort was conducted in three parts: an experiment

examining skill acquisition and retention, the development of a model of optimal coordination, and a follow-up experiment comparing types of training.

The model of coordination developed by Cooke, et al. is a synthesis of two existing theoretical models: the procedural/stage theory of coordination and the dynamical systems theory of coordination. The procedural theory states that teams execute a shared plan from a point of common understanding in order to achieve a common goal. The authors offer Klein's (2001) example of the stages involved in selecting an air strike package: Preparation, Planning, Direction, Execution, and Assessment. While these stages are explicitly defined by the theory, the authors note that they may occur implicitly during team interactions rather than as overt actions. Under the dynamical systems theory of coordination, teams self-organize in order to reach their goal. This theory states that there is no *a priori* script or plan that team members share, and their coordination results from their interactions with each other and the task environment.

The first experiment was conducted using the UAV-STE (Synthetic Task Environment) developed by the authors. The authors examined the acquisition and retention functions of teams based on manipulations of Retention Interval Length (i.e., the time, short or long, until participants engaged in a follow-up session) or and Team Composition (intact or mixed). Teams were trained an tested together, and then were asked to participate in a follow-up session. If a team was "mixed," the follow-up session was conducted without keeping the initial team intact. The researchers found that mixed teams (i.e., teams whose members were not familiar with each other) displayed a significant performance decrement in the follow-up session, while those that were intact did not have such a decrement. The length of time until participant engaged in a follow-up session (i.e., short = 3 to 6 weeks, long = 10 to 13 weeks) had some effect on performance, with short-intact teams having a lower performance deficit than other teams. However, the performance deficit due to retention disappeared after the second mission in the follow-up session. While performance was lower in mixed teams, the individuals who had mixed team sessions showed greater improvements in knowledge accuracy from session 1 to session 2. However, short-intact teams showed consistent improvement in teamwork knowledge measures from session 1 to session 2. The authors suggest that these results indicate that mixing team composition results in short-term performance decrements but with long-term teamwork and taskwork knowledge gains.

In the second experiment, team mental models were examined using the UAV-STE. As in the first experiment, participants engaged in an initial session, with a follow-up session some time after (8 to 10 weeks after the first session). Team training was manipulated by the introduction of perturbations, which took the form of static introduced over communication lines. The three team conditions were procedural training, cross-training, and perturbed training. The authors found no significant differences in teamwork between the two sessions or the team conditions. Increased workload during the experiment resulted in significant decreases in coordination for all team types. However, procedural teams were slower to overcome roadblocks (i.e., problems during the task) than cross-trained and perturbed teams. The authors suggest that perturbed teams were the highest performers, though the effects on coordination were not sufficient to draw conclusions regarding coordination.

2.6.3 Requirements for Team Training

As has often been said, a team of experts is not necessarily an expert team. High proficiency on the part of individuals with respect to the goals and requirements of the tasks of individuals is certainly desired for all team members. But equally important is skill at teamwork and team tasks, such as coordination and the development of shared mental models.

First, with regard to how to prepare individuals for team training, what is required is clearly explicating the precursors to team training in the training of the individuals. Doing so requires attending to the systematic techniques of training needs analysis which examines three inter-related levels to account for the multitude of issues affecting the process and performance issues experienced by teams (see Salas, Sims, Klein, & Burke, 2003). At the *organizational* level, this analysis identifies whether or not the institution supports training implementation and helps to identify where and when training is needed. At the level of the *task,* cognitive task analysis and team cognitive task analysis (e.g., Crandall, Klein, & Hoffman, 2005; Klein, 2000), must be used to identify the training content. Finally, a *team analysis* is necessary to detail who within the team needs training and the degree to which team process or individual training is needed (e.g., skills-based training at an individual level or communication training at the team level). Critical to this level of analysis is articulating the interdependencies within the team so as to lay out the coordination requirements to be trained.

Second, with regard to what to train, team training must consider content knowledge, perceptual-motor skills, reasoning skills and strategies, coordination and collaboration skills, and attitudes appropriate for teamwork. New notions such as that of shared mental models and transactive memory systems are relevant to accelerating the development of proficiency in teams.

"Shared mental model" is the term used to describe knowledge structures held by team members which are related to understanding the task, their teammates, and their teammates' roles (Cannon-Bowers, Salas, & Converse, 1993). The recent introduction of this idea in the field of human factors represents an important advance for our ability to analyze team cognitive work, but as with all concepts of complexity, it needs qualification. Within the work of teams are many individual tasks and goals that are the responsibility of an individual and involve activities and knowledge that one or more of the other team members does not need to know. A surgical nurse may need to track the patient's blood pressure but the surgeon may need to know only that the pressure is at some acceptable level. The nurse may need to be able to anticipate that the surgeon will soon need a particular clamp, but the surgeon does not need to know where the nurse has to go to get that clamp. To say that there is a "shared" or "team mental model" does not mean that all team members know all the same things Any approach aimed at providing all the information and knowledge to everyone on a team is certainly misguided.

Wagner (1986) "defined the transactive memory system as a combination of the knowledge possessed by each individual and a collective awareness of who knows what" (Austin, 2003, p. 866). Transactive memory is used to help team members have a sense of teammate expertise.

"Team situation awareness" (SA) is another useful concept for understanding teamwork. But again, there is the qualification: The concept of team SA should not be taken to mean that at any one moment all of the team members need to be aware of all of the same factors in their immediate task environment. Again, any approach aimed at providing all the information and

knowledge to everyone on a team is certainly misguided. Endsley and Robertson (2000) describe a Team Situational Awareness Training Course, based on five major SA issues in aviation maintenance: 1) incongruous mental models, 2) lack of communication, 3) lack of feedback, 4) lack of teamwork and shift meetings, and 5) task and environment issues. Their evaluation of the training determined the perceived value and usefulness of the training, the training's effects on attitude and on actual workplace behavior. In all of these categories of evaluation, the training intervention was rated (by the trainees) as useful or effective, and follow-up measures indicated that workplace activities and teamwork changed after the training administration.

With regard to team skills, communication (Cannon-Bowers, Salas, Tannenbaum, & Volpe, 1995; Salas, Burke, & Cannon-Bowers, 2000) is key to process and performance. Stated most simply, this is effectively exchanging information "between two or more team members in the prescribed manner and with proper terminology [along with] the ability to clarify or acknowledge the receipt of information" (Cannon-Bowers et al., 1995, p. 344). It involves information sharing and closed loop communication as well as volunteering/requesting information.

Coordination is a skill also critical to performance outcomes. Marks, Mathieu, and Zaccaro (2001) defined this as "the process of orchestrating the sequence and timing of interdependent actions" (p. 367).

Finally, important team attitudes for training include psychological safety, that is, a team member's perception that his/her team is safe for interpersonal risk taking. (Edmonson, 1999) and collective efficacy, defined as the team's belief they have the capability to complete their tasks (Salas, Burke, & Cannon-Bowers, 2000).

There is a significant motivational component to team training just as there is to individual training. Instruction that that is useful in training for complex cognitive work prompts the team members to approach learning as effortful and mindful ("active learning") but at the same time a collaborative. This is generally associated with improved skill acquisition and increased adaptivity. As for individuals, teams-in-training need to focus on mastering tasks, rather than getting individual problems right ("mastery training"). Individual team members, and teams as a whole need to have a sense of achievement to balance a sense of failure, which might be more impactful because the work is cognitively difficult and hence trainees might be especially prone to failure in the early phases of instruction. Another finding is that feedback to individual team members works better if provided to all the members of the team, in the team context. "Research indicates pervasive effects for the motivational components on self-regulatory processes, learning, and performance" (Kozlowski & DeShon, 2005, p. 6-7).

2.6.4 Methods for Team Training

The studies making up the Delise et al. meta-analysis included a variety of training methods such as lecture-based training, group discussion, videos and task demonstrations and/or practice. Other methods include those designed to incorporate training content that encompasses a broad swath of learning requirements; that is, incorporates knowledge, skills, and attitudes. Both event- and scenario-based training (e.g., Oser, Gualtieri, Cannon-Bowers, and Salas, 1999; Salas & Cannon-Bowers, 2000) are relevant methods for capturing the complexities inherent in high-levels of performance. Here complex scenarios are developed to elicit targeted behaviors, thus

providing contextual grounding for learning and understanding. From the standpoint of continual learning, self-correction and guided self-correction training are effective in helping teams continue developing their expertise (e.g., Smith-Jentsch, Zeisig, Acton, & McPherson, 1998). These methods teach team members to evaluate their own, and their teammate's, behaviors so as to judge their effectiveness. Relevant for high-performing teams is also research in team coordination training which combines knowledge with behavior to support team-level understanding in how to sequence and integrate actions (Entin & Serfaty 1999). Also important is work on cross-training which is designed to support development of shared understanding and, more critically, shared expectations, by training the roles of teammates (for a review see Stagl, Salas, & Fiore, 2007). Finally, as for use of simulation-based training, recent developments may enable a more efficacious implementation of learning and training. For example, simulation-based handoff scenarios are designed to specifically focus teams on communication and handoffs (Berkenstadt et al., 2008). Other methods incorporate embedded instructional agents to monitor and assess trainees (e.g., Neville, Sorensen, Glucroft, & Barba, 2002; Ryder, Santarelli, Scolaro, Hicinbothom, & Zachary, 2000).

Team Training Using Simulations

Fletcher (1999) approached the subject of team training via networked computer simulation applications. Following a basic definition of simulations, he describes how simulations have been used in the military, noting the increasing popularity of simulations for both training and assessment. Because of this popularity, Fletcher notes, the psychology community has started to approach simulations from the standpoint of psychometrics and measurement in general. In other words, simulations are now discussed in terms of reliability, validity, and precision. This turn toward using simulation for measurement is meaningful because it addresses a specific need of the military community: combat skill assessment. While Fletcher argues that comprehensive combat skill assessment is impossible (due to its requiring actual wartime activity), simulation allows for training and evaluation of military forces in situations that are not feasible to reproduce in reality (i.e., virtual wartime conditions). Fletcher proposes that readiness be used as a surrogate for combat effectiveness, as readiness can be trained and evaluated without war, whereas combat effectiveness requires actual combat conditions. As an example of the efficacy of readiness training, Fletcher offers the applied case of Navy vs. Air Force training during the lull in the North Vietnam air war. Simulated combat allowed Navy pilots to outperform Air Force pilots who did not receive combat simulation training. However, this data is non-experimental, and only suggest (rather than prove) efficacy.

Following this discussion of simulation and combat readiness, Fletcher describes tactical teams, which are groups of individuals that make operational decisions. These teams vary in size and scope, and are effectively decision making or action teams in the wider psychological literature. Like other teams, these tactical teams must make decisions in real time under a variety of outside constraints and pressures.

After a brief discussion of shared mental models in teams, Fletcher arrives at the core of his discussion: the use of networked military simulation to train and assess decision making. As a key point, Fletcher points out that simulations are not an inferior replacement to real-world training, but are in actuality a tool that allows trainers and trainees to surpass the limitations of reality and provide information, opportunities, and context that would otherwise be unavailable. Simulations are broken down into three primary categories: live simulations, constructive simulations, and virtual simulations. Live simulations involve experience in the field, using

actual equipment. Constructive simulations are non-interactive models of reality (i.e., the "modeling" component of modeling and simulation). Virtual simulations are computer-based simulations that are interactive, providing a digital version of live simulation. No one simulation category is superior to another, as they all provide different information and afford different types of training.

Given that the military is a large organization consisting of teams of teams, simulation in the military must provide the organization with opportunities to train with large numbers of individuals. Networked simulations allow collective proficiency to be trained, and Fletcher notes that they are especially applicable to such applications because they: 1) focus on groups, 2) allow for distributed training, 3) work in real time, 4) allow for dynamic environments and tasks, 5) provide performance data, 6) are affordable, 7) can be high-fidelity, and 8) allow for multi-unit interactions. However, the use of networked simulations for problem solving and decision making training requires effective performance measures, which must be diagnostic, discriminative, valid, and reliable. Following a description of the criteria that such measures must meet, Fletcher describes the specific problem domain of problem solving and decision making, offering an overview of the processes involved therein.

Schreiber, et al. (2009) present the history of use of flight simulators for training and assessment, from its beginnings in about 1910 to the present, including current-day activities that enable practice on "distributed mission operations" (DMOs). These are team-based training involving fairly elaborate scenarios and activities of a complex operation. There are many challenges of assessment of performance and proficiency levels in these new, elaborate, multi-person, high-technology environments that are situation reactive and capable of many manipulations. Assessment as currently conducted relies heavily on subjective evaluation, which Schreiber, et al. feel have limitations. There is an outstanding need for good team performance assessment measures and techniques in these environments, as indicated by the many current Department of Defense research programs aimed at issues of team performance metrics.

Accelerated Learning for Teams?

The acceleration of team proficiency will require its own instructional strategy (Salas & Cannon-Bowers, 1997, p. 313) although just as for individual training, it will presuppose the identification of the requisite knowledge, skills, and attitudes associated with the given training need, and match these to the methods appropriate for this need (Salas & Cannon-Bowers, 2000). Also critical for any effort in accelerating team proficiency is matching the method of training with the prior experience of the team members—experience at the domain tasks, at the team tasks (which differ from the tasks of individuals) and experience at being a team member.

2.6.6 Some Generalizations?

- Individuals who are more proficient at solving problems related to the team's primary goals (team task work) place a high value on cooperation and engage in more work-related communication (team work). Thus, training in the achievement and maintenance of common ground will enhance team performance.
- In high performing teams, the team members develop rich mental models of the goals of the other team members. Training that promotes cross-role understanding facilitates the achievement of high proficiency in teams.

- High performing teams effectively exchange information in a consensually agreed-upon manner and with consistent and meaningful terminology, and are careful to clarify or acknowledge the receipt of information. Training that promotes such communication facilitates the achievement of high proficiency in teams.
- Practice while team membership changes can facilitate the acquisition of team work skills.
- The question of performance decay in team work skills due to hiatus is an open subject for research.
- Training for accelerated team proficiency, like training for individuals, benefits from problem or scenario-based practice using realistic and complex scenarios (e.g., serious games, simulated distributed mission operations).

It makes sense to seek to form and maintain teams in terms of consistency of team membership, giving the team a chance to practice team work and become an "expert team," just as the musical quartet must practice extensively in order to develop a capacity for collective improvisation. However, as the findings of Cooke et al. show, the mixing of teams can have its own benefits in that it allows individuals to gain knowledge and work on their team work skill, that is, ability to forge a high-proficiency team. In addition, in military teams membership is often necessarily ad hoc, there is a mixture of proficiency levels, and team membership typically changes frequently.

In the case of teamwork and team training, generalizations are hard to come by primarily because the study of complex cognitive work by teams is a relatively new area. It is certainly open for investigation and may benefit by attempting to devise rapidized training or other forms of acceleration. In the next section we discuss the literature on accelerated learning, what little there is, and we see there that many of the demonstrations of acceleration are in fact, focused on teams and team work.

2.7 Accelerated Learning

The first reference we have found to the notion of accelerated learning is a paper by Carlson (1990) in reference to expertise in the mental health care industry. Carlson's paper was a proposal, based on the finding of great variation in the effectiveness of mental health services (for depression alcoholism. etc.) across counselors, health facilities, geographical regions, etc. Carlson invoked the Dreyfus and Dreyfus (1986) developmental stages (see Tables 2.2 in the present Report) arguing that health care workers needed to be trained beyond the use of fixed procedures and rules, up to the stage where reasoning is context-sensitive. Carlson proposed that this situation could be improved if health care analysis were based not on patient throughput, but on the identification of genuine expertise with regard to patient care. Carlson proposed an attempt to instill that expertise through feedback-based training utilizing scenarios created through consultation with highly experienced clinicians.

This notion of accelerated learning highlights an important theoretical and practical tension. On the one hand is the notion that we must accelerate learning; that is, increase the speed with which proficient performance can be acquired. On the other hand, there is a significant amount of evidence that developing expertise requires up to 10 years of experience and practice with zeal

including practice at "tough tasks" (Hoffman, 1998), suggesting that it is not possible to accelerate the achievement of high proficiency.

In this section of this Report we present a set of case studies that report training that can be counted as successful demonstrations of acceleration.

2.7.1 Accelerated Learning in Business

A general theme in the field of knowledge management is that learning on the part of corporate employees might be accelerated through social networking. One reason is that information sharing can help prevent decision errors (cf. Townsend, 2009). Social networks derived by sociometric analysis (who talks to whom, who shares information with whom, who asks questions of whom) can show where the corporate knowledge and expertise lies within the organization (Becerra-Fernandez, et al., 2004, 2008; Stein, 1992, 1997). Expert judgments of the competencies of other experts conform to evidence from experts' retrospections about previously-encountered critical incidents. Competency judgments, and competencies shown in incident records, can be used to predict practitioner performance (McClelland, 1998). There is ample evidence that social networking tools and capabilities (Blogs, Facebook, Twitter, etc.) can help people escape organizational bottlenecks and can rapidly connect people having with common interests and problems. Wiki workspaces can show networks of expertise which be used as a platform for collaboration, and used to manage processes of mentoring. Peer-to-peer, such networks can establish an organizational culture in which workers can collaborate to suggest improvements to business procedures or policies.

Though this is all plausible, it is anecdotal and there is a paucity of research demonstrating actual "learning acceleration" other than collections of organizational success stories that show business success (i.e., "the efforts paid off...") but not actual learning.

A notion of accelerated learning can be found in the field of business management, in efforts called High Performance Work Systems (HPWS). A main idea in this approach is to move decision making power down from higher levels of management and administration to "front-line" workers. Reports suggest that in many forms of business, this approach works.

> If tasks are uniform and stable, and if there are well-known solutions to problems that arise, then a traditional, routinized, and centralized work organization is most effective. But if tasks vary frequently then a more flexible "polycentralized" organization is deemed appropriate... a work organization that makes use of workers' imagination and initiative is superior (Applebaum, et al., 2000, p. 36-37).

DiBello, Missildine and Struttmann (2009) argue that increasingly in complex manufacturing sectors, like biotech, greater decision making responsibility is being demanded of front line workers without the requisite power to carry out these complexity of the objectives involved. But achieving empowerment of front-line workers requires training to a higher level of proficiency. Typical techniques for empowering front line workers do not hold them accountable to high level, non-negotiable outcomes because they focus on empowerment as an end in itself, without

considering the importance of empowering workers in such a way that engages their knowledge and skill (their intuitive or tacit expertise) to achieve the higher level goals of the organization.

DiBello, et al. demonstrated the use of scenario-based simulations in training to instill "intuitive expertise" in front-line workers in the biotech industry. The study represents accelerated learning in that realistic scenarios were worked in compressed time, that is, durations in the actual scenario that were not filled by scenario-pertinent events could be compressed (e.g., bacterial fermentation might take a month but can be compressed to 20 minutes).

The context was a company that made proteins and other biological materials for research and drug testing. As the company grew through acquisitions, it came to consist of a number of separate teams with specialization only in certain areas, reflecting the specializations of the individual companies that had been acquired. This resulted in overall inefficiency and a backlog on orders that led to customer complaints (as much as $800,000 worth of orders per day on back order).

The researchers studied the work and conducted interviews and found that some individuals managed to grow the right material in the needed volumes and on time. These individuals, not highly trained biologists, had developed proficiency and "intuitive expertise" that was not being shared across the company.

The simulation-based training was conducted in a mockup of the company's shop floor. In the simulation-based training, the researchers developed a prototypical scenario that unfolded according to a normative ideal (such factors as cost, product flow, profits). The exercise was presented as a game, in which teams had to meet all customer orders on time. The training utilized a fast-paced operational simulation exercise that did not specify the skills or means for greater responsiveness; rather the trainers emphasized only goals and challenged the groups to develop a solution.

Teams of 20 to 25 workers ran through the scenario and typically applied their usual approaches and methods. The instructors allow the workers to continue using their normal methods, but increase the tempo and pressure to perform, all the while plotting the team's performance against the ideal. "By the end of the first day the workplace is in crisis and the participants are realizing that their resources are being expended to react to mounting problems" (p. 21). In Round Two of the exercise, the participants review their performance and discus what went wrong. New solutions are generated, and thus it is this round that brings out the tacit knowledge of the more proficient workers, presented in context for all to benefit from. In a Third Round the simulation is lightly altered so that it cannot be worked from memory) and the participants try out their new approaches.

In the two-year study in the biotech firm, high levels of performance were achieved and sustained by workers. In the end, all groups exceeded desired outcomes and developed skills in the process not normally targeted in training. They accelerated the launch of new products by several "game-months." Comparing the two run-throughs of the exercise that each team experienced, even the best-performing team on the first run-through performed worse than the worst-performing team on the second run-through. After one year, the novel solutions developed

in the exercises had been put into place and a high performance level had been sustained. The back orders problem plaguing the company had been resolved.

This method has worked successfully and to good advantage in a number of domain application projects. DiBello, et al., see its value in eliciting the tacit knowledge of the most proficient workers, calling out methods and strategies that do not work well, and generating new and more effective methods and procedures.

> We accelerate and intensify the original process through which a workplace culture of practice shapes cognition normally... experienced low-level workers developed approaches that go beyond what would be possible with simply starting over with new workers or attempting to "train" them with best practices used elsewhere... [Our approach works] because of their considerable content knowledge; they emerge from our simulation exercises with new frameworks but retain their rich experiential content. The new framework redeploys their rich content knowledge in innovative ways (p. 29).

2.7.2 Accelerating the Acquisition of Teaching Skills

The concept of accelerated learning has most recently been invoked in the field of teacher education. Viadero (2010) reports on a 4-year longitudinal study by the Carnegie Foundation, focusing on the teaching of English in primary schools. In seventeen schools, teachers who received additional coaching in how to teach literacy became more effective as teachers. There was also a wide variation among schools and among teachers within schools. Such findings could mean acceleration in a number of ways. First, it could be that many of teachers were not so good to begin with (a floor effect). In fact, "the teachers who got the most coaching were the new teachers" (p. 2). It could be that there was an acceleration of teacher learning but that might be because of the intervention and not because of anything substantive about the training itself (e.g., there might be a Hawthorne effect).

2.7.3 Acceleration of Perceptual Learning

Research on training and instructional design has shown that advanced learners learn different things and in different ways than less advanced learners. One important research question is precisely when and how to shift the level of the training materials and methods (for some given domain or skill). Another question is whether acceleration can be achieved by hastening the progression from journeyman to expert. The field of instructional design generally focuses on instruction from novice levels upwards. Indeed, Fadde (2007) notes that the field has generally felt that training to high proficiency is a matter for mentoring and massed practice, and not of instructional design.

Fadde (2007) discussed an acceleration method that derives directly from the research in the field of Expertise Studies, and specifically from the Recognition-Primed Decision Making model (Klein, 1989). Expertise in many domains is defined partly in terms of the practitioner's ability

to rapidly perceive patterns that non-experts cannot perceive (Klein & Hoffman, 1992.). Furthermore, highly proficient practitioners are often able to apprehend a situation and intuitively know what course of action to take. In theory, one could do a form of time compression in which one taps into a corpus of cases that present opportunities for perceptual learning, and thereby "hasten expertise" (Fadde, 2007, p. 1). The cases do not all have to be "tough" (i.e. emphasize the recognition of critical patterns), but should span a range including representative cases.

Fadde (2007) notes the similarity of such an approach to methods of educating attention that have been utilized in sports (e.g., Chamberlain & Coehlo, 1993; Williams & Ward, 2003). Within sports science there is ample evidence that training in recognitional skills (e.g., a baseball batter's ability to rapidly recognize the type of pitch that was just thrown) can be trained using simulations and even video, and that practice using those shows positive transfer to a "live" recognition task (Farrow, et al., 1998). Part-task recognition training can be accomplished using low-fidelity simulations. For instance, skill at laparoscopic surgery can be trained by having a trainee use a laparoscope to manipulate peas set atop golf ball tees (Williams & Ward, 2003). Fadde discusses the specific task of "temporal occlusion." In this task a dynamic stimulus is suddenly removed from view and the trainee then has to engage in a recognition, categorization or prediction task.

He also cautions that "… it is generally not appropriate to apply expert schema induction to initial learning by novices. Recognition training does not replace direct instruction in rules, concepts, and procedures, but rather enhances it, at the appropriate time in the learner's development" (p. 2).

Domains in which one might attempt to accelerate the achievement of proficiency through time compressed perceptual learning would include, for instance, air traffic controllers. In these and many other domains, expertise is defined in part by the ability to perceive featureless family resemblances that exist over multiple and dynamic data types (Hoffman & Fiore, 2007). In addition, experts have the ability to continuously re-learn as the important patterns change, and with advances in the technology and displays.

2.7.4 Demonstrations of Acceleration in Teaming

A training project that can be interpreted as a success case of accelerated learning, in the sense of improvements to training, is a study by Shebilske, et al. (1992) on part-whole training. This project was aimed at the issue of how to train complex skills, either as wholes or in parts. The studies use such laboratory tasks as *Space Fortress*, which involves such tasks as joystick control of a simulated spacecraft, battling adversaries, and avoiding mines. In one protocol developed previously, trainees practice the part tasks but in the context of the whole task. Periodically, the part tasks the trainee is practicing get changed. This "multiple emphasis on components" (MEC) protocol has a positive effect on learning, compared to training in which the part tasks are practiced out of context (Gopher, Weil & Siegel, 1989). In the new protocol that Shebilske et al. developed, trainees work in pairs, with one trainee practicing half of the task while a second trainee practices the other half-task in the same whole task. Periodically, the two trainees alternate the half-tasks. This Active Interlocking Modeling protocol improves training relative to individual practice. Interestingly, performance is linked to general reasoning ability, suggesting that each trainee's opportunity to observer and reason about their fellow trainee's performance,

all the while conducting their own half-task, contributes to the method effectiveness. The AIM protocol has been successfully used in training by a commercial airline.

2.7.5 Intelligent Tutoring Systems

Intelligent Tutoring Systems (ITSs) leverage techniques form expert systems (e.g., production rule systems) and artificial intelligence to go a major leap beyond the first so-called teaching machines (Forbus & Feltovich, 2001). ITSs rely on a knowledge base of concepts and rules, gleaned from subject matter experts. The computer is provided with or infers information about the learner's level of knowledge and presents problems that are appropriate to that level, and then adds progressive difficulty, specifically for the purpose of pushing the student's understanding to a higher level.

Early, but relevant, developments in ITSs the SOPHIE and "Sherlock" tutors for training in troubleshooting skills (see Polson, Polson, & Richardson, 1988). Sherlock (not an acronym) is an ITS for troubleshooting avionics test equipment for the F-15. The creation of Sherlock was premised on the fact that the legacy training focused on: (1) formal principles rather than "direct manipulation experiences" that promote causal reasoning skills (Morris & Rouse, 1985) and (2) the analysis of individual components rather than system-level functionalities and testing procedures (Rouse, 1982).

Sherlock's production rules were generated from a cognitive task analysis of the reasoning and procedures of highly-experienced technicians. Sherlock presents to trainees a series of progressively more difficult troubleshooting scenarios involving fault isolation. The training occurs at a high-fidelity mockup of the actual technician's avionics test station. Coaching—explanations of an expert's strategic reasoning—was provided along the way. The "Sherlock" name refers to one of the icons on the computer display that managed the test procedures: A clickable icon showing a Calabash pipe.

Gott (1995) conducted a test of the effectiveness of Sherlock. Apprentices (having 3 years experience) received the Sherlock training, and on a subsequent test they outperformed a group of Masters (having had 10 or more years experience). Apparently, with Sherlock apprentices were able to acquire the strategic knowledge of highly proficient technicians. Another capsule view of the Sherlock findings (Lesgold, Lajoie, Bunzo, & Eggan, 1992; Lajoie, 2009 is that approximately 25 hours of Sherlock training was the equivalent of 4-years of on-the-job training. Gott attributed the dramatic effect to the "situatedness" of the training, the ecological validity of the scenarios and the "learn-by-doing" approach.

> Sherlock presented a concentration of useful cases in a brief period of time. The real world mostly provides opportunities to do the routine. Expertise involving the non-routine is harder to get from everyday work experience because the right situations occur rarely and often are handled by established experts when they do occur, not by students" (Lesgold, 2001, p. 967).

Instruction using intelligent tutoring has shown significant gains (upwards of one standard deviation) over most other methods (Corbett, et al., 1999). Meta-analytic techniques document gains of up to one standard deviation when compared to other methods as well as significant reductions in time on training (Dodds & Fletcher, 2004; Wisher & Fletcher, 2004).

One caution, appropriate in the context of the present Report, is that Sherlock (and many other ITSs) trains for fixed tasks. Certainly, teaching the functionality of the avionics testing equipment and the rationale behind fault diagnosis tasks will be better than training rote procedures with minimal sensemaking. But fixed tasks do not characterize modern "complex cognitive work" systems.

Likely it takes four years for the avionics technicians to experience the variety of task situations that Sherlock could present. Given that experts come to acquire understanding of rare cases, that is, those particular problems or decisions that occur only approximately 5% of the time (Hoffman et al. 2007), simulations of rare cases may help time compress the learning process (e.g., Hoffman & Fiore, 2007). From the Sherlock project, we know that it is possible to time compress the experience-feedback cycle for acceleration from apprentice to journeyman proficiency levels. Acceleration beyond that, to high proficiency, would only be possible if the ITS incorporated the expert's "tough case knowledge." Woolf, et al. (2002) suggest that tutors need to be more generative, that is, create instructional material (problems, hints, help) based on student performance simultaneous to engaging in student modeling such that it is able to assess the student's knowledge and modify instruction accordingly.

Fletcher (2010) reported a study that used an ITS for training the Navy's Information Technology rating. Thirty-two students who had been selected for the "A" School training received a 16-week program of instruction that included two weeks of training using a prototype tutor. The tutor, developed by DARPA, was designed specifically to provide "best practices of human expert tutors" at solving problems in information technology troubleshooting (Fletcher, 2010, p. 1). At the end of the "A" School and again after some "C" School training, groups of trainees were given a series of troubleshooting problems (spanning a range of difficulty) in a virtual laboratory, in an instrumented laboratory and aboard Navy ships. Their performance was compared to that of experienced technicians (average of about 7 years experience with 40 C Schools). (The experimental and control groups were statistically similar in terms of age and Armed Forces Qualification Test scores.)

The experienced technicians solved about 85% of the problems, with about 60% of the solutions rated as excellent. The students who had received the ITS tutoring solved 97% of the problems with 90% rated excellent. In the study of troubleshooting onboard a deployed ship, most of the contributions of the trainees to solving actual troubleshooting problems were rated by supervisors as substantial or essential. The project achieved its goal of raising the performance of newly trained technicians from a 50th percentile to a 98th percentile level. The trainees had mastered all the "A" School content in two weeks. With regard to the more advanced "C" School training, the tutor-based training produced technicians with skill comparable to that of technicians with 12 years of experience. This is a clear demonstration of both rapidized training and accelerated proficiency, including a demonstration of transfer to the operational context.

2.7.6 The Army's "Think Like a Commander" Training Program

A training strategy that has in recent decades received considerable attention is the teaching of critical thinking skills by presenting trainees with realistic scenarios and also with support that takes the form of guidance concerning the pattern detection, decision making and reasoning of experts. Studies of the effectiveness of this form of training, primarily in the application area of military tactical decision making, have been generally successful (e.g., Cohen, Freeman & Thompson, 1997, 1998; Klein, McCloskey, Pliske, & Schmitt, 1997).

The Think Like a Commander (TLAC) training program can be thought of as an attempt at accelerating the achievement of high levels of proficiency at cognitive work, that is, both rapidized training and accelerated proficiency (see Shadrick, 2009). The Program relies on scenario-based exercises using difficult cases, with guidance and instruction from a highly experienced officer, on an assumption that this constitutes deliberate practice. The goal is to allow officers to model their battlefield understandings, plans, visualizations, and decisions after expert tactician's thinking patterns (Shadrick & Lussier, 2004).

Trainees are presented with vignettes from battlefield studies, that is, interviews with experienced commanders who retrospected about previously-experienced cases. This is the interpretation of accelerated learning as *Facilitated Knowledge Sharing*. Often, military lessons learned quickly become lessons forgotten as they are left to reside in libraries.

In the TLAC Program, trainees work through a dozen or so scenarios in simulated compressed time, making decisions about deployment of assets, visualizing the battlefield and coping with contingencies as the scenario unfolds. They are coached in how experts look at problems and how the adversary would think about the problems. Trainees are encouraged to work intensively on the problems, and thus we might say this training represents highly motivated "practice with zeal." The TLAC training can involve scaffolding by a trainer, or it can be conducted by trainees without benefit of such scaffolding.

In a series of studies, Shadrick and colleagues (Shadrick, et al., 2007; Shadrick & Lussier, 2004, 2009; Shadrick, Lussier, & Fultz, 2007) evaluated the U.S. Army's "Think Like a Commander Program" (TLAC), and also the "Captains in Command Training Program for Adaptive Thinking Skills" (which is a PC-based version of TLAC) (Shadrick & Fite, 2009). They demonstrated that the training leads to significant improvement in the ability to rapidly analyze a tactical situation in order to identify the critical information needed for tactical decision-making. They demonstrated that TLAC training improved the ability of officers (in the Armor Captains Career Course) to create better company-level Operations Orders.

The 2004 study was a post-training performance evaluation of trainee ability to analyze tactical situations in battlefield vignettes. This adaptive thinking measurement instrument was validated in a second study, which demonstrated that leaders having experience in Operation Iraqi Freedom and Operation Enduring Freedom performed better at the TLAC vignettes than those without such experience. For those without such experience, performance increased with rank. For those with experience, performance of captains and majors was about the same as that of lieutenant colonels. In other words, experience trumped rank. The authors take this as evidence

of the powerful effect of deliberate practice, assuming that it instills the same capabilities as (deliberate) experience. The findings also suggest that training using the (relatively simple) vignette materials may be more effective and efficient than experiential training, i.e., training using more elaborate methods of simulation and virtual reality. Citing the work of Ericson and his colleagues (Charness, Krampe, & Mayr, 1996; Ericsson, 1996; Ericsson, et al., 1993). Shadrick, Lussier & Fultz, 2007) conclude:

> The maxim "train as you fight" has risen to such a level of familiarity in the U.S. Army that the value of the notion goes almost unquestioned; that is, that the best training method is to 'just do it' in a realistic environment. Yet studies of the development of expertise clearly indicate that "as you fight" meaning performing in fully realistic simulated battles is neither the most effective nor efficient method of developing expertise. Such "performances" can help a novice become acquainted with applying military knowledge and can reinforce existing knowledge in an experienced person, but will not in and of themselves lead to the development of expertise. In many fields where expertise has been systematically studied, including chess, music, and sports, development beyond intermediate level requires large amounts of deliberate practice (p. 17).

The implication is that for some domains and types of tasks (or missions), accelerated learning might be achievable using relatively simply vignette methods as opposed to more costly simulation methods.

It is also interesting to note their finding that the training can be effective even when trainees work the vignettes without benefit of instructor scaffolding.

The effectiveness of the TLAC training approach was verified by a laboratory study conducted by TNO Human Factors in The Netherlands (van den Bosch & Helsdingen, 2002). They developed a number of scenarios involving ground-to-air defense. The trainee played the role of the battle captain. As the scenario events unfolded, the trainee was presented with ambiguous and sometimes conflicting information, to allow for alternative interpretations of events. During scenario "freezes," the training was provided with information about what the experienced commander might notice or decide, or alternative interpretations of situations. Trainee performance was evaluated by the training leaders, in terms of the results of the trainee actions in the scenario outcome, quality of the trainee's plans, quality of arguments, and other factors.

Unlike the finding of Shadrick and Fite (2009) that instructorless training was effective, the TNO studies demonstrated that participating in the scenario-plus-scaffold conditions resulted in improvement whereas merely working through the scenarios without the scaffolding did not. Interestingly, the opening instruction (to the main experimental group) to take a "critical thinking approach" led to early improvement that was maintained across the scenarios. This certainly suggests that critical thinking might be thought of as a stance as much as a set of specific or learned skills. If critical thinking were the latter, one might expect to see gradual rather than rapid and immediate performance improvement. As the authors point out, additional research with various additional controls is certainly in order.

In a second experiment at TNO, one group of trainers was itself trained in the "critical thinking instructional method" and its components, and another group of trainers was instructed to follow their usual instructional methods. In this study, the domain was anti-air and anti-surface naval warfare and the study was conducted using high fidelity simulations at the Operational; School of the Royal Netherlands Navy. In this case, the trainees worked in teams and team performance was evaluated (information exchange, leadership, time management, quality of plans, and so forth). This study also found positive benefits from the critical thinking training, in this case with the control for possible biasing on the part of the trainers.

The authors discussed their work as the training of "critical thinking" (See also Cohen, et al., 1997, 1998; Klein, et al., 1997), but in practice it seems to be the training of critical thinking in context of the military tactical decision making. We point this out because it is important to separate the claim of transfer of training in "critical thinking" skill—reflective and self-critical assessment of performance— from the claim of performance improvement due to the training of context or domain-specific critical thinking strategies. Nevertheless, the findings from the TNO studies certainly justify the continued study and expansion of use of the Think Like a Commander form of training.

2.7.7 Simulation-Based Training

The notion that simulators could significantly improve training of pilots is explicit in papers dating back decades, the reference being to acceleration in the sense of achieving a base level of proficiency more quickly than in current or legacy training. The earliest reference to the notion of acceleration (that we can find) is in an Army Report by Wladyslaw Wielowski dated 1990 and titled "Trainers (Simulators) that Facilitate and Accelerate Learning."

Today, there is a consensus of researchers that serious games, synthetic environments and virtual reality trainers can be used to very good effect in training. Use of high-fidelity simulations of problem scenarios for training is widely recognized as having promise in the further improvement of training, and generally with respect to a notion that the progression from apprentice level to high proficiency levels can be accelerated (Dawson & Caird-Daley, 2009). Chatham (2009a) calls it the "20th-Century revolution in training."

This revolution progressed from computer-aided instruction that at adopted traditional classroom teaching methods (read and test), and then to instruction that leveraged more of the capabilities of computers (games, video demonstrations, etc.), and then to more high fidelity games. Most recently it has branched from the workstation context to 1) the immersive context of simulators, 2) the "distributed" context of distance learning and collaboration using the internet, and 3) the immersive context of large-scale live simulated environments. Chatham (2009a) calls this new kind of training "Engagement Simulation." He dates it to the 1970s and a serendipitous "experiment" from the Vietnam War, in which low air war kill ratios led the Navy to institute Top Gun training, while the Air Force did not do anything similar. Great improvement in the Navy flyers, but not in the Air Force, signaled the efficacy of the new kind of training. It has led to more of this kind of training, for example, the very effective NTC (discussed below).

Chatham discusses several successes, including DARWARS Ambush and the Tactical Language and Culture Trainer. Despite its successes, Chatham cites problems with this kind of training, including expense, logistics, and time. The fact that engagement simulation takes time is interesting in context of the present Report on acceleration of learning. The hypothesis would be that Engagement Simulation training takes time in the sense of lengthening the period of pre-deployment training, but arguably it saves time (and lives) by getting trainees up to a higher-than-traditional level of proficiency before deployment. That is, skill is acquired in training that would ordinarily only be acquired once the "boots were on the ground," and at risk. Furthermore, engagement simulation can train in warfighting skills and situations that would, in the actual deployment only be experienced opportunistically.

Chatham suggests a form of simulation-based training which is less than immersive, that is, serious games which are portable, on-demand, and manipulable.

2.7.8 Engagement Simulation-Based Training: "Top Gun"

An example of a military training program that can be regarded as a success case of accelerated proficiency is the U. S. Navy "Top Gun" program (Chatham, 2009a,b). Dissatisfied with the kill ratio in the air war over Vietnam, the Navy established a training program involving intensive practice at "dog-fighting." Trainees subsequently engaged the enemy at a 12-to-1 ratio (while Air Force performance remained at the 2-to-1 level. This finding was calculated over 100 engagements involving multiple types of aircraft and weapons systems, and thus the results are confidently attributable to the training (Gorman, 1990). (Data on World War II pilot performance showed that the odds of being shot down were very high for first engagements, but that the probability of being shot down decreased significantly for pilots as they gained experience.) Following the Top Gun success, other services commenced programs of large-scale simulation-based training.

2.7.9 Engagement Simulation-Based Training: The Army's National Training Center

At the National Training Center (NTC), there is a simulation of a town in the Middle East, populated by hundreds of actors (many of them of Middle Eastern origin). Battalions in training for deployment come to the NTC for weeks-long exercises against a resident battalion specifically prepared to challenge the trainees. Plot threads involving insurgents, mayors, etc., with the scenario design based on anticipated situations the trainee battalion will experience in theater. Figures 2.3 and 2.4 present photo montages of the NTC.

Figure 2.3. A photo montage of the NTC "village" area.

Figure 2.4. A photo montage of the NTC operations facilities and activities.

Performance is not measured by simple comparisons of success; trainees are not judged by how well they performed against the adversary (the resident Red Force is more capable). Rather, they are judged in terms of their achievement of reasoning strategies and skills. The NTC has reported significantly increased rates of success post training (light infantry 30:1, combined arms teams 15:1, Regiments/brigades 5:1 success rates).

Gorman (1990) laid out these key features of this, and other successful Engagement Simulation-based training programs:

- Training is given to teams and not just individuals,
- Training uses the actual systems that will be experienced in the operational setting.
- Training involves the use of complete scenarios, run from start to finish
- Feedback is continuously available to and among trainees, and is extensive during feedback periods.
- Feedback and discussion covers situation awareness, decision processes, state of mind, and other aspects of the cognitive work.
- Trainees are encouraged to think deeply about situations and problems and share ideas, feelings, and insights. Trainees are encouraged to retrospect about and evaluate their reasoning.

- Feedback comes from trainees and not just trainers.
- Independent red and blue forces, with the aggressor force fully prepared and capable of using actual adversary tactics.
- Red force warriors are themselves of high proficiency.
- The trainees experience tougher situations than those typical of what they are likely to experience in theater.

2.7.10 Current Department of Defense Efforts at Rapidized Training

The Air Force Weather Agency has launched a program to train "Forecast Ready" forecasters possessing high-level knowledge beyond intermediate skill levels. The goal of the training is for forecasters to be capable of using mesoscale models (computer models) and remote sensing tools. The goal is for the forecasters to be able to "explain the reasoning behind the forecast" (McNulty, 2005, p. 5). This description suggests that the target is the advanced journeyman to expert level of proficiency, which is generally achieved in forecasting after years of experience (see Hoffman, et al., 2000). It is also a proficiency that is climate or local specific, generally. To make it possible for training to accelerate learning, great reliance will be placed on mechanisms of distance learning (Pagitt, 2005). "The 7th Weather Squadron is moving at lightning speed towards a new training initiative... a premier, just-in-time combat field skills training course..." (7th Weather Squadron, 2005, p. 16). This initiative can be seen as following the NTC model. Its focus is on making sure that forecasters are tactically and technically prepared prior to actual deployment. The method is to site students at a large training area for a week of instructions (vehicle maintenance, generator maintenance, simulated convoy operations, etc.) and experience with command and control procedures, in addition to practice at tactical meteorological forecasting.

Kirschenbaum, et al. (2009) describe an innovation in training for sonar technicians and fire control technicians aboard a submarine. The goal was to rapidize the acquisition of skill during training. Traditionally, after the schoolhouse and early in the first deployment, the technicians were still considered trainees, and spent most of their effort at extensive mentored training. Furthermore the schoolhouse training was traditional (lectures, Powerpoints tests). The newer method was based on an thorough cognitive task analysis of the technicians' jobs, The results supported the creation of "job-oriented simulations" (computer-based instruction) resulting in accelerated skill development during training and increased proficiency level when the technician-in-training arrived on the submarine.

2.7.11. Conclusions Concerning Accelerated Learning

Acceleration in the sense of rapidized training has been demonstrated: The quickening of training without reduction in the proficiency level achieved at the end of the training. Indeed, indications are that rapidization methods lead to higher levels of proficiency than legacy training.

Acceleration in the sense of achieving higher levels of proficiency has also been demonstrated, and in complex military jobs/tasks. Demonstrations of this also entail one of the meanings of acceleration, the rapidized transposition of lessons learned into the training context.

All of the methods used in training for rapidization and for accelerated proficiency depend on one or another form of time compression. One form is that of packing more varieties of experiences into the training and not merely shortening the training. For instance, proficiency in a domain may depend on having had a variety of experiences, any one of which might only arise rarely. Through case libraries, the training can "escape" real time. A second sense of time compression is to truncate events that transpire within a scenario. For example, a troop movement during which little of consequence happens can be truncated.

2.8. Summary of Findings From the Literature Review

Proficiency

- We have rich descriptions of proficiency and the development of proficiency, and robust methods for proficiency scaling.

- We know what makes the achievement of high proficiency difficult., and this knowledge feeds directly into instructional design.

Training

- The variables affecting training (types and sequences of practice, domain complexity, learning styles, etc.) all interact in complex ways, making generalization difficult.

- Problem-Based Learning shows promise for training to perform in dynamic and complex domains where tasks are not fixed.

- We have rich descriptions of types of feedback and know that feedback, in general, is necessary and helpful, but generalizations about the timing of feedback are always tentative (e.g., immediate feedback may not contribute to long-term achievement of proficiency).

- The goal of training is not to make learning easy but to make it easier and quicker than it would otherwise be. In initial, intermediate and advanced levels of training, there must be problems that present "desirable difficulties." Training at advanced levels cannot oversimplify. Indeed, high proficiency is defined in part by the ability to cope with tough cases.

- In general, mentoring is highly valuable for the trainee and the organization. In many cases mentoring (vs. instruction) is necessary.

- In complex domains scenario-based training is highly valuable and arguable necessary (e.g., in training for situation awareness, training for adaptivity).

- Training should train for meta-cognition. This is referred to as "reflective training" and as "training to learn."

Transfer

- It is difficult to make generalizations about transfer, since patterns depend on the type of task. Perceptual-motor skill, declarative knowledge, and reasoning skill are often conflated in the literature.

- High proficiency skill and knowledge in some domain are useful in solving problems in that domain and are of limited transferability. Yet, the phenomena of expertise prove that there must be transfer of knowledge across problem types within a domain.

- There are a number of different possible kinds of transfer and we have rich descriptions of these.

Retention/Decay

- Our knowledge of decay and the general form of the decay function is fairly robust.

- Many interacting factors influence retention/decay; not all forms of knowledge/skill decay at the same rate and there is some inconsistency in the findings.

- Over-learning is the best predictor of retention.

- Better methods are needed for measuring over-learning.

Teams

- The study of team cognition in complex cognitive work is a relatively new area for human factors research. There are many gaps in knowledge and methodology.

- Better methods are needed for assessing work quality in the new team-based contexts for complex cognitive work.

Accelerated Training

- Rapidized training and accelerated proficiency can be possible through the use of computer games, simulations, and immersions, all of which are enhanced through application of intelligent tutoring and artificial intelligence capabilities.

- The use of case-based instructions, realistic tough cases with focus on errors and "desirable difficulties."

- Expertise is the source for training materials. This entails a new meaning of "accelerated learning," that is, quickening of the translation of battlefield lessons learned into the training.

- For acceleration of team proficiency, training exercises must encourage the acquisition of teamwork skills and "people skills." Training must take into account individual differences in cognitive style and intrinsic motivation.

- For acceleration, training exercises must tap into a rich corpus of tough cases.

Training for accelerated proficiency must rely upon meaningful, corrective feedback that is appropriately timed (neither too close nor too distance from the performance being evaluated).

3.0 ABOUT THE WORKING MEETING

The second workshop, titled the "Working Meeting on Accelerated Proficiency and Facilitated Retention," was held in October 2009 in Phoenix AZ. It was organized by Dr. Dee Andrews, 711th Human Performance Wing Senior Scientist, Air Force Research Laboratory, Mesa, AZ

3.1. Meeting Focus and Topics

Participants were presented with challenge questions noted above in Section 1 of this Report. In the Meeting read-ahead these challenge questions were stated succinctly as:

- How can we develop operational definitions and measures of proficiency at a fine grain?
- How can we develop methods for identifying expert mentors and revealing their knowledge and strategies?
- How can we best design training to promote skill retention and prevent skill decay during periods of hiatus?
- How can we train for adaptivity and the need to cope with the ever-changing workplace and changing and challenging missions?
- How can we train for resilience and the need to cope with complexity when unexpected events stretch resources and capabilities?
- What USAF jobs require high levels of proficiency and have analogs in the private sector?

Core topics that were to be addressed at the Working Meeting included the following:

Measures and Levels of Proficiency
This topic addresses the measurement methodology to determine levels of proficiency. This needs to go beyond the traditional rough cuts often used in organizations and expertise studies (i.e., expert versus novice) to achieve finer discriminations along the skill continuum (e.g., Hoffman, 1998). The challenge is to establish reliable and valid markers that might be used for such things as placement, promotions, and for use in assigning practitioners to skill levels in research studies. In this regard, measurement of performance for all complex sociotechnical systems must also go well beyond traditional measures of human performance (Alberts & Hayes, 2003).

Selection and Scaffolding for the Development of High Proficiency
Traditional hiring practices have not served well to predict who will eventually be a high performer. New methods need to be investigated. For instance, it may be that common screening tools at hiring will need to be replaced or augmented by various indicators that only become apparent after some period of time functioning on the job. Along with identification, there will need to be programs for supporting progressive development beyond what are typically taken to be "professional development" activities in many organizations.

Mentoring and Apprenticeship
Many aspects of work are best learned "at the bench," under guidance from a skilled mentor. These include what is often called "tacit knowledge," that is, many aspects of "know how," where opportunities for learning largely manifest themselves in the course of real, active work, in the social context of work (Schön, 1983). We need to be able to identify excellent mentors, study them to reveal the knowledge and strategies of mentors, and develop programs for training mentors. We also need to determine what job practices are best suited for mentoring, as opposed to using other kinds of training techniques.

Learning for Flexibility, Adaptability, and Resilience
Robustness is the ability to maintain effectiveness across a range of tasks, situations, and conditions. Resilience is the ability to recover from a destabilizing perturbation in the work as it attempts to reach its primary goals. Adaptivity is the ability to employ multiple ways to succeed and the capacity to move seamlessly among them. Fundamental to the achievement of robustness, resilience and adaptivity is the opportunity to practice at problems that stretch current competency (Ericsson & Lehmann, 1996; Feltovich, et al., 1997). However, modern work presents challenges for achieving such adaptive skills. For much of history, individuals have developed mastery and resilience by focusing intensely on a relatively circumscribed task or suite of skills, e.g., chess or welding. Modern work (especially in sociotechnical work systems) has become much more unstable and complex. People change jobs, jobs change, orders change, technology intrudes and changes the work, customization in products and services requires versatility beyond the assembly line, etc. Can we train (or select for) expertise in flexibility and resourcefulness? What kind(s) of learning and materials does it require? For example, one method that has been used is to have workers rotate through other job roles that are integrated with their own work.

Addressing All of These Factors in the Context of Teams
In addition to fluidity, customization, etc., another prominent feature of modern work involves teams and teamwork. For functional, workable acceleration to be possible, training exercises must encourage the acquisition of teamwork skills. An expert group is not the same as a group of experts (Salas, et al., 2006). While many skills may be in common, teamwork engages others, for example, certain kinds of "people skills," coordination skills, understanding of others and their "ways," and the ability to develop and maintain satisfactory mutual understanding, "common ground" (Klein, Feltovich, Bradshaw, & Woods, 2004).

Identify Candidate Domains for Study
What domains might be a focus for attempts to accelerate the achievement of expertise or assess methods for facilitating retention? We seek domains that are interestingly different and yet share these features:
- Are domains within the military that are of high complexity, are mission critical, and require high levels of proficiency, and involve decision making under uncertainty.
- Are domains that rely on extensive knowledge and flexible reasoning (not just "skill") since the cognitive work is sensemaking of complex, dynamic and nonlinear patterns of causation,
- Have an analog in the private or public sector,

- Are hard to learn and do well, as attested to, for instance, by high wash-out rates and few extant experts,
- Have in the past required very long training and on-the-job experience.

For all of the topics, the participants were encouraged to list opportunities, obstacles, and research requirements for the acceleration of proficiency and facilitation of retention.

3.2. Roster and Agenda

The roster of participants was shaped by consideration of the many disciplinary paradigms that pertain to the concepts of accelerated learning. Input would be needed from specialists in training, instructional design, human resource management, and longitudinal research design. The Working Meeting would need to have participation by experimental psychologists, organizational sociologists and educational psychologists. The Meeting would need input by researchers whose work has focused specifically on one or more of the following topic areas: knowledge elicitation, the development of proficiency, learning retention and decay, case-based reasoning and instruction, and mentoring/tutoring.

The Participant Roster and the meeting Agenda are presented in Appendix A. The formats of the Meeting activities were Background setting presentations, whole-group presentations, and Break-Out Group sessions that focused on one or more of the core topics and challenges.

The group photograph is shown in Figure 3.1, and the legend on the following page.

Figure 3.1. The group photograph.

Group Photo Legend

Back Row
R. Hoffman, K. Gluck, S. Fiore, D. Andrews, D. Ziebell, A. Gibbons

Middle Row
F. Greitzer, M. Krusmark, K. Addis, K. VanLehn, L. DiBello, G. Klein, R. Patterson, R. Proctor,
P. Feltovich, H. O'Neil, L. Magee, W. Bennett (there's a bit of staggering in this row)

Front Row
T. Branaghan, R. Hubal, B. Pierce, P. Fitzgerald, Col. Walker, S. Goldberg, J. Freeman, A.
Healy, Lt Col Hilger, J. Bradshaw. N. Charness, K. Velkey

Not Pictured
Herb Bell, Rand Spiro, Maj. Brian Healy, Alex Lincoln

3.3 Pre-Meeting Activities

White Paper material was composed and shared with all of the participants prior to the meeting. That document is presented here in Appendix B. Along with it was sent:

Hoffman, R. R., Fiore, S. M., Klein, G., Feltovich, P. & Ziebell, D. (2009, March/April). Accelerated learning (?). *IEEE: Intelligent Systems*, pp. 18-22.

Additional read-ahead papers were made available at the meeting web site. These were:

DiBello, L., Missildine, W., & Struttman, M. (2009). "Intuitive Expertise And Empowerment: The Long Term Impact Of Simulation Training On Changing Accountabilities In A Biotech Firm." Report, WTRI Incorporated.

Feltovich, P. J., Coulson, R. L., Spiro, R. J., & Dawson-Saunders, B.K. (1992). Knowledge application and transfer for complex tasks in ill-structured domains: Implications for instruction and testing in biomedicine. In D.A. Evans and V.L. Patel (Eds.). *Advanced Models of Cognition for Medical Training and Practice*. Berlin: Springer-Verlag.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*, 23-31.

Koedinger, K. R., Pavlik, P., McLaren, B. M., Aleven, V. (2009). Is it Better to Give than to Receive? The Assistance Dilemma as a Fundamental Unsolved Problem in the Cognitive Science of Learning and Instruction.

Lajoie, S. P. (2003). Transitions and trajectories for studies of expertise. *Educational Researcher, 32,* 21–25.

Townsend, M. (2009/April). Leveraging human networks to accelerate learning. C*hief Learning Officer,* pp. 34-37.

In addition to providing their biographical sketches (see Appendix C), participants were asked to submit Pre-Meeting Position papers (see Appendix D).

4.0 INTEGRATION OF THE WORKING MEETING PRESENTATIONS AND DISCUSSIONS

Looking across the Position Papers (Appendix D), the Presentations (Appendix E), the discussions based on the Presentations, and the Break-Out Group discussions, this variety of topics was discussed:
- Domains of Study
- Some Paradoxes and Ironies of Training
- Research Challenges
- Methods and Designs for Acceleration

4.1 Domains of Study

Many differences and similarities can be seen comparing professional domains. For example, with regard to technology important dimensions of difference include the newness of the technology (e.g., new software versus legacy systems) and the extent to which workplaces and jobs depend on information technology. In some specializations, information technology is not the critical aspect of the job whereas in others it is. In his analysis of system administrators, Haber (2005) noted that IT systems often consist of a multitude of components ranging from "HTTP servers, web application servers, authentication servers, content servers, database management systems, network load balancers… distributed across multiple networks and multiple operating system platforms, and each of the components may have hundreds or thousands of configuration parameters" (p. 1). Thus, in the course of troubleshooting these systems, one needs to both comprehend how all of these varied components interact and to integrate system information into a single picture.

In some domains, such as firefighting and many military subdomains, experts who confront problem situations sometimes cannot engage in deliberative analysis of options. In emerging, high-stakes, time-pressured situations there is no time for rational analysis of options, costs, risks. Normative decision theory argues that problem solving can only be optimized if a rational analysis is conducted. But such analysis is precluded in time-pressured situations. Studies of fire fighters, nurses, managers, and other domain experts have shown that experts more typically engage in recognition-primed decision making (Klein, 1989). In this process, an inspection of information leads directly and immediately to a path of action, and typically the first option selected by the expert is the optimal or best one.

In some specializations the work involves high-level cognition but also involves tough physical work (e.g., turbine maintenance). A few particular domains were called out for discussion and analysis at the Working Meeting.

Second Language Learning as a Domain Case Study

Learning a second language to a point of high proficiency (i.e., fluent conversation on a dialect) has been of immediate important to the U. S. military. Circa Operation Desert Storm and just thereafter, it was initially extremely difficult for the U. S. military to meet the demands for fluent

translators/interpreters, especially for Category II (security-cleared) translators (salary over $200,000). After meeting goals of recruiting, and subsequent deployment, significant numbers of linguists quit. Language-fluent interpreters that the U. S. military has sent to Middle East tend to be older individuals not prepared for the exertion or stress (Straziuso, 2009). An additional problem is that the diversity of languages and dialects means that many people who are fluent, are fluent only in one or dialect.

Training in this domain was discussed in a presentation at the 2008 Accelerated Learning Workshop, by Dr. Ray Clifford. The higher levels of proficiency are defined by the ability to speak colloquially and conversationally so as to "pass" for a native speaker, and at the highest level, the ability to think creatively in the second language. These two highest levels of proficiency are achieved only rarely by individuals whose upbringing was monolingual. Those who do achieve these levels do so only after significant time living in the second language and its cultures. What this suggests is that here is at least one domain that is already "accelerated" to the extent possible. By this we mean that the apparent limits of selection and training seem to have been approximated.

Electric Utilities as a Domain Case Study

The traditional industry preference is to engineer out the tacit knowledge. If they cannot do that, they would want to outsource it. Last thing they prefer is to capture, preserve, and train it. This is changing now to an emphasis on knowledge capture and mentoring. The median age of the workforce, across all of North America, is 50 years. It was estimated that 65 percent of the senior engineers are or will soon be eligible for retirement. Thus, in a number of utilities there are knowledge management efforts aimed primarily at capturing expert knowledge and reasoning strategies, so that they might be integrated into training for the next generation. The knowledge management effort includes an increased emphasis on mentoring and also the need for companies to have on staff their own trained knowledge elicitors.

Electric utilities are slow-moving fixed organizations within which expertise shows itself. For instance, an individual might begin a career in substation and transformer repair, move up to a workforce management position, and have years of getting to know the company from top to bottom, represent the company in its relations with a Public Services Commission. An engineer might begin a career in turbine maintenance and progress to a planning function, supervising plant shut downs and turbine deconstruction. Both of these examples are of mission-critical jobs. (Indeed, the shut down of a turbine costs the company millions of dollars a day!) For this reason, a notion of the "super expert" has emerged in discussions of the utilities workforce (Ziebell, 2009).

The Electric Power Research Institute (EPRI) was founded in 1973. All the utilities are members, as are some utilities in other nations. International as well. EPRI is a technology accelerator. In 2000 it began a process in collaboration with the Institute for Human and Machine Cognition, to identify methods to capture undocumented worker knowledge. Guidelines were produced in 2002 and 2004 for capturing and using high-value undocumented knowledge in the nuclear industry.

In 2008 EPRI began to investigate the notion of accelerating the achievement of mission critical expertise. It is easy to acquire and instill "middle of the bell curve" knowledge. But at an electric plant there will be, say five out of 1500 people who are irreplaceable. Proficiency spans many critical jobs, and not just engineering jobs, examples being succession planning and conflict negotiation.

Transfer of knowledge might use well-understood methods, but still requires effort if the need is to transfer high-end technical wisdom to a few specified individuals whose value lies at the fringes of the discipline but is nevertheless mission-critical (e.g., individuals who keep the company out of the newspaper; individuals who make sure the lights do not go out at Giant stadium on Monday night). The high-end experts sometimes change the mission and thereby make the total organization resilient. There is the case of a fire in a relay station building that had lots of asbestos. The expert's novel solution was seal off the building, flush the insides into one single storm drain and grab the debris from there. The process took a couple of weeks (vs. many weeks), it protected the public and the environment, and kept the incident out of the newspapers. It takes 25-35 years to achieve high-end proficiency, related in part to the complexity of the domain and the longevity of the technology. (Only recently have we begun the change from analog controls to digital controls.) Many stories are told of the engineering challenges in New York City. Engineers have to maintain and integrate numerous subsystems built in different eras. A senior relay system protection engineer retired, and was replaced by four engineers, each having had ten years of experience. That did not suffice. When a car hit a pole and two lines tripped, both lines were lost. Across the two lines there were dozens of different kinds of relays and dozens of different kinds of relay protection schemes, some 50 years old. The retired engineer had to be brought back in to fix this emergency situation.

Such stories make clear the fact that a great deal of expertise can be explained in terms of Recognition-Primed Decision making. High levels of proficiency can be defined largely in terms of the ability to notice complex and dynamic patterns that others cannot apprehend.

U. S. Air Force Pilot Training as a Domain Case Study

In the domain of fighter piloting, there are no measures for expertise per se, but objective measures that are interpreted to reflect proficiency include weapons employment zones, time from target detect to next action, time in enemy threat range, frequency of mode changes for sensor systems, frequency of communication, target of communication, etc., Additional measures that are likely correlated to proficiency are number of flying hours, time in training and frequency of training events, and peer or supervisor ratings of performance. The typical definition of combat mission ready proficiency is related to the number of flying hours. The USAF standard is 500 hours of tactical flying. However, this metric has been suspect for some time since the Air Force has been flying a variety of mission types in the past 15-20 years where it is quite easy to have 500 hours, but those hours were obtained flying patrols (limited to no tactical employment) over northern or southern Iraq. So this variability results in lots of fighter pilots having 500, 1000, or more hours but not of the "kind" that would be indicative of mission ready performance.

School/training is regarded as the pilot's pedigree, and by analogy, weapons school would be "graduate" school or doctoral level tactical training. At any time, the cohort of duty-ready pilots

includes a mix of professional and ad-hoc training and experience. In the opinion of some, current training methods are based on a model dating to the 1980s, and are becoming out of date.

The "lost apprenticeship" is a current concern—there fewer opportunities to develop expertise. As the fighter technology becomes more complex, with the intent of making aircraft easier to fly, the training requirements can outpace the capacity/opportunities to train. Thus, training to gain/maintain readiness is a growing concern. Aging systems and a high operational tempo are limiting live training opportunities. Range limitations are reducing the fidelity of live training. These all stand in conflict with the increasing costs and complexity of missions, which require efficiency and proficiency. (It costs $35,000/hr for an F-22 flight.)

Might there be mixes of approaches and technologies for training that impact the achievement of proficiency and also promote retention of skill and expertise? Training methods are needed that are adaptive to learner needs (given the diversity of pilot backgrounds and levels of proficiency). Training needs to be "rich" in presenting experiences representative of the operational context. Training needs to be readily accessible to warfighters. Training should be seamlessly integrated with live systems for continuous learning. Knowledge needs to be warehoused and re-used in training (e.g., in the form of managed scenarios).

The problem of skill decay due to hiatus is very salient within the piloting domain. Generally, it is assumed that for some given length of hiatus some particular refresher course is needed. It is indubitably the case that practice at flying is critical post hiatus for the pilot to re-accommodate to the dynamics of flight.

The actual progress of decay/retention of piloting or air combat skill has not been studied empirically "in the wild." It would be a significant challenge to study air combat skill decay under real world conditions. Such study would entail a longitudinal experiment study with operational pilots, a manipulated retention interval (say, 3 or 6 months and 1 or 2 years). Post hiatus there would be some training (e.g., 5 days) and then a scenario exercise having a known complexity score. Objective measures would include mission outcomes, strikers to target, enemy aircraft killed, friendly mortalities, weapon hit ratios, etc. Only through such a study could there be an empirical anchor for our understanding of skill decay, skill reacquisition rate, and moderators of skill decay.

An additional, or alternative, approach is to develop and deploy richer measures of process skill that are applied in the analysis of operational performance. This might provide an empirical anchor on levels of proficiency (and indirectly guide the management of post-hiatus training regimes). Process/skill measures might include time in vulnerability regions, weapons employment measures, measures of communication and coordination efficiency and effectivity.

Bennett (2009) reported on a study of the decay/retention of performance at distributed missions (i.e., joint forces) on the part of US Air Force F-16 fighter pilots. The study involved running teams of pilots in missions using a high-fidelity F-16 test bed. Distributed missions, and the simulator-based training for them, involve having teams, and not just individuals in each simulator run. The researchers examined initial training gains, skill decay, skill reacquisition rate, and moderators of skill decay. Variables of the mission scenarios included time of day, speed (sub- versus supersonic), range of adversary threats, force ration, operating range restrictions, and others. The 69 participating pilots included ranks from Lieutenant to Major, and so had ranges of age about 26-32 years), years of service (9-10 years) and flying hours (abut 240-

1900 hours). Participants were assigned to a stable team and to one of two groups of teams, which would experience different retention intervals (3 or 6 months).

First, the teams of pilots experienced practice missions for one hour in a simulator, followed by five days of curriculum including simulator-based team training. The purpose of this initial "pre-post" phase was to gauge the benefit of training. Then there followed a retention interval of either three or six months, after which they were tested in simulated missions on each of two successive days. Measures were taken of both process and outcome. Outcome measures included strikers to target, enemy aircraft killed, friendly mortalities, and weapon hit ratios. Process measures included communications overlap (a sign of coordination inefficiency) and speed of the fighter plane at time of missile launch. (It is preferable to launch when the jet is traveling faster than Mach-1, so as to add momentum to the missile.)

Results for some of the measured dependent variables showed that the training made a difference in improving team performance, and that prior experience made a difference (the teams that included more experienced pilots showed less decay). The length of the retention interval also had a noticeable impact for some of the measures, representing a slight but detectable loss of the performance gain attributable to the training.

The results were mixed but suggestive, but the study is of practical significance because it makes clear the pragmatic difficulties of research into these topics, as Bennett pointed out. Statistical power is an issue (sample size, possible ceiling effects), some of the pilots may have known about the benchmarks for the types of missions they were going to fly, there are complex interactions of individual performance in determining team performance, and there is no way to control for relevant experiences during the hiatus period. There are many practical issues and many research complications in the study of retention/decay in "real world" domains of professional practice. The study was planned to take 18 months, but ended up being three full years of work. This was due to limited availability of the teams, loss of team members due to reassignment.

There are many practical issues and many research complications in determining best methods for training during hiatus to mitigate decay and for refresher training post hiatus to insure a fast re-achievement of high proficiency. What day-to-day practice can you do during hiatus? While on hiatus, pilots do continuous training so the hiatus is not purely "no flying." But time is limited. Hiatus periods involve assignments that are themselves time and effort intensive, and there is only so much time during the day.

There is also the practical issue called "Frankenjet." At the end of a hiatus of say two years, the jets being flown will have changed avionics, weapons, and other systems. This raises the idea that hiatus training should focus on "what is currently changing in the operational context."

UAV Piloting as a Domain Case Study

The use of unmanned aerial vehicles (UAVs) is growing in the military, federal, and civilian domains. Worldwide, in the next 8 years UAVs will be a $15.7 billion industry. In the United States the plan is to acquire 9,420 mini UAVs, 775 tactical UAVs, 570 minimum altitude, long-endurance UAVs, and 60 Global Hawks... From January to October 2007, the number of hours for mission sorties doubled in the Air Force, creating a staffing crisis (Donmez, Cummings & Graham, 2009, p, 718). The UAV operator career track will no longer be one defined by

retraining of pilots. Instead, it will be its own trained specialty and training programs are just now being instituted. The UAV program at the University of North Dakota has expressed interest in collaborating on projects that might incorporate accelerated learning notions, just as the core training program is being designed and instituted. It is also note worthy that UAV operations will likely expand, and significantly so, into the private sector.

Working Meeting Analysis of Domains

The military has need for more individuals who can work at very high levels of proficiency in all of the areas designated by COIN (counterinsurgency), DIME (diplomatic, informational, military and economic) and PIMESII (political, military, economic, social, information and infrastructure).

> In 1994, Dave Haut (Chief of the Analysis Division for the Department of Defense's Pacific Command,) asked the question, "Suppose there are problems in country X and the ambassador has the choice of having a carrier battle group sail down the country's coastline in a show of force or playing golf with the country's prime minister; how does he decide which will be more effective?" The combat models of the time had no way of framing such a situation, much less any hope of answering the question....As Bosnia, Afghanistan, Haiti, Iraq, Somalia and Darfur in Sudan have shown, 21st century conflicts are different from those of the early and mid-20th century. We don't fight them in the same way, and in some cases we don't fight at all. Military force is only one of the elements of persuasion that are useful in addressing 21st century conflicts. Further, we can't measure results in the same way. Lost lives and damaged equipment are part of the story, but not all of it. To understand success, or lack thereof, we need variables that measure (almost) everything" (Hartley, 2007, p. 1).

In the Working Meeting Break-Out Groups, the most frequently mentioned consideration was the pace of change in domains of professions practice, including in military jobs and specialties. A second frequently mentioned consideration had to do with teams, and specifically, the situation in which team turnover rates dictate against the need to generate expert teams.

Turnover is different in different domains in terms of teams. In many military jobs and missions, military people do not stay together in teams. It is hard to keep people in military together as people get transferred. War has its own effects that work against the notion of building expert teams. A central idea on the study of team cognition is that a team of experts is not necessarily an expert team, and that training for high levels of team proficiency involves training in team tasks in addition to training in the teamwork. Individuals need skill at contributing to the rapid transition from the status of "new team" to the status of "high functioning team."

The challenge for the Working Meeting participants was to identify more than one candidate domain for application and testing of methods of accelerated proficiency and facilitated retention. The domains must be interestingly different and must have military and civilian

analogs. Clearly, domain choice will hinge on a number of factors, not the least of which will be need. One will have to determine the needs, within a domain or subdomain for a workforce at each of the proficiency levels spanning junior apprentice to senior expert.

The Break-Out Groups discussed a number of general domain features and issues, and went into some depth in discussing certain domains. A variety of domains were mentioned and discussed, including, Software engineering, STEM fields (Science, Technology, Engineering, and Mathematics), Cybersecurity, Cultural Awareness, Personnel management, UAV operation, Weather forecasting, General command.

Many emerging military domains involve coping with dynamism. Many involve the fusion of information is a characteristic of some domains. An example is cyber security. People must take a bunch of ambiguous information about dynamically evolving situations and structure it and put it together to generate an outcome. Many new military domains involve training competencies versus training tasks. For example, Iraqi cultural training caused soldiers to think more and draw from experience when actually deployed.

Strategic considerations in identifying domains for study would include selecting:

- A tedious job does not make for high level of motivation, and this would be a factor working against the achievement of high levels of proficiency.
- Domains that relate to STEM fields would make an accelerated learning project strategically linked to a broader national concern.
- Domains that can be imported into academic laboratories for study,
- Domains that could be treated as "open source" for getting data on baseline performance,
- Domains in which there are important tasks that can be modeled using simple linear models and in which such models perform as well as experts. Training can involve "beating the linear model" as a test of proficiency or expertise.

Maintenance is a potential domain that fits these criteria. We know from studies of this domain that one can chart the development of proficiency. Troubleshooting a particular device would be like forming a "mini-career." This may not be a representative domain, however, because more parts are now disposable and also because the practitioner can rely on rely on manuals rather than critical thinking. Debugging computer programs might be a more representative domain in this regard.

Cybersecurity has prospects and is a current need. There are universities that have programs, and one might study their students. The domain has a technical aspect, but also includes pattern recognition skill and causal reasoning. This domain certainly has the dynamism: it changes quickly. Retention might be an issue just due to the changes in domain. (This is an empirical question.) The challenge will be to coming up with sub-domains with sufficient complexities to monitor performance. In terms of security issues, it may be difficult to get actual data on performance (across a proficiency spectrum). There is a desire to avoid exposing workforce or capability limitations, or expose mistakes or vulnerabilities. Also, because this domain is so dynamic, and new technological capabilities are always coming on line, training or acceleration may have a limited viable lifetime: One cannot anticipate what someone may be able to extract

from that data just few years in the future. Trust in automation may be a researchable area. Although it does not represent an identifiable career or subdomain of specialization.

Emergency Response is a good candidate domain. One might set up critical emergency response teams, composed of experienced practitioners or of trainees. Performance could be evaluated of novices and of trainees who receive the same data as experts.

Search and Rescue/Medical Evacuation is a good candidate domain. It is tactical and there is a great deal of technological change.

Electric Power Generation and Distribution is a good candidate domain. The U. S. Army Corps of Engineers (CoE) provides power generation and distribution services in deployments at all scales. In addition, CoE engineers provide services and support to regional utilities in areas of operations. Given this military analog to the civilian utilities, and given the emerging importance of proficiency training in the utilities, this might be an appropriate domain for studies of accelerated proficiency.

Cultural Awareness and Skill is a good candidate domain. Cultural decision making is difficult for the soldier, who is trained to be in war then must transition to negotiation tasks. One could run terrain teams (anthropologist, sociologist, etc.) through scenarios to work out cultural issues, and see what they do. The military needs more "cultural chameleons" for collaboration (social adaptivity and reasoning) sand also for counterinsurgency and stability operations.

UAV Operation is a good candidate domain. F-16 drawdown and UAV ramp-up is an opportunity to study as there will be pressure to make F-16 utilization more specialized and more efficient. Because UAVs are becoming so capable, the nature of conflict is changing, as the nature of intelligence operations. UAVs will be entering the private sector. A current design issue is whether work methods and software systems can permit a single operator to "fly" more than one UAV, so the nature of the UAV operator job is likely to remain a changing one. Because of the technology of UAV is changing, it is just like a box, assuming a person can fly 4-5 of different ones. There is significant emphasis on the achievement of proficiency. The equipment is so expensive, without skill training, it will be a disaster.

Weather Forecasting is a good candidate domain. It may be appropriate to consider the area of weather forecasting and analysis as one of the subject-matter areas to research. Several factors recommend this, including its importance to all of the military, its complexity, its inherently team-based nature, and criticality of advanced pattern perception skills. There is an ongoing test bed of instructional design and development that exists in the COMET Project of the University Corporation for Atmospheric Research at Boulder, Colorado. This project has developed a massive body of training material, which is used by a very large international audience. It represents a large and growing design/development activity that likes to partner with special needs. Among the project's sponsors already are the Army, Navy, Air Force, and Marines. The COMET project would provide an excellent collaborative partner, able to supply a very large number of participants who represent an appropriate target population and a ready-made distribution system for trying out and iterating research products. In addition, there are a number of excellent undergraduate and graduate education programs and these are typically interested in collaboration related to workforce issues.

Table 4.1 expresses the Working Meeting consensus about criteria for domain selection. One especially noteworthy consideration is with regard to knowledge, skill, and reasoning. Most academic/laboratory studies of learning involve declarative memory (knowledge) and reasoning rather than motor or procedural skills. Domains (tasks or jobs) that involve a mix of the knowledge, skill, and reasoning are relevant for many jobs, but especially so for military jobs (piloting, marksmanship, mine detection, and so forth).

Table 4.1. Conclusions regarding criteria for selecting domains.

The task/job work requires highly organized knowledge, reasoning skills, and motor or procedural skills as well.
The job/task work involves coping with dynamics and complexity.
Achievement of proficiency involves practice at tough cases.
The work depends on skill at pattern learning (recognition-primed decision making), sensemaking, and the other primary macrocognitive functions.
Practitioner motivation and affect play a key role.
Domains requiring a capacity to be adaptive and resilient.
Domains with recently transformed strategic environment, where people have more than one duty assignment.
The work involves teaming of specialists, and requires expert management of teams.
There is organizational support for processes of achieving higher levels of proficiency.
Domains match into STEM (science, technology, engineering and mathematics).
Ease of study (factors including data access, availability of known and valid measures, etc.).

4.2 Paradoxes of Training and Paradoxes of Careers

Looking across careers and domains that have been studied, people who are highly motivated become experts and those who are not intrinsically motivated are less likely to become experts. Individuals who feel a personal investment are more likely to look at other various aspects of their domain that are not necessarily central to their specific job or roles. They actively seek an ever-widening scope for their expertise.

Organizational customs and policies often cut against this. For example in the intelligence domain, one either stays in and moves up, or gets out. The motivation shifts from getting better at analytical roles to getting better at administering. And yet ironically, the individuals who are motivated tend to be the ones who volunteer to get extra training. Is there support in the organization to pursue expertise, an organizational culture that fosters workers to become experts in something related to the overall organizational mission?

There are a number of paradoxes and ironies of learning, training and careers that complicate any effort toward acceleration of proficiency and the facilitation of retention. We call out these ironies and paradoxes by beginning with two career case studies that were discussed at the Working meeting.

A Career Case Study: Military Intelligence

By the time of achieving senior rank, an intelligence officer will have spent as much as half their time engaged in work other than intelligence analysis. This would be an impediment to the achievement of high levels of proficiency. Of the time spent in analytical jobs/roles, a majority of the assignments would be in one type of intelligence analysis (Signals, Imagery, Targeting, UAV, etc.). Targeteers and Weapons Officers do stay in that assignment for long periods and do become experts. But most jobs do not involve consecutive assignments.

Time spent in non-analytical assignments involve work at a higher level (e.g., global ISR operations, planning and assessment). Each of the high-level roles/jobs has multiple core competency areas. It takes time to achieve competency, and there is never enough time for study. You cannot have consecutive assignments in the same core competence.

Then after some years of work at the higher-level, job one gets transferred back to some particular analytical role. Due to the shortage for field-grade officers, there is a tendency to seek and be assigned roles that fall within prior expertise. This would contribute to the progress toward higher levels of proficiency at that analytical role. *"But when you get back [to the previous analytical role] no one knows you. You have to rebuild your reputation. Mentors are no longer co-located with you."*

A Career Case Study: Aircrew Expertise

Twelve years of operational assignments is the country's return on investment for all the training. Any time after two years at the principal assignment, an individual can be moved off that career path to do something else, typically something that is not flying. It can be teaching, UAV piloting, or a staff job. For some individuals experiencing a longer hiatus, they are brought back to wingman status and in the training, are basically starting the career path all over again.

In an example career, an officer was a pilot on B-52s and then transitioned as navigator to the B-1. The transition course has three tracks, based on prior experience, that is, flight hours.

In this example career, each assignment involved over 1,000 hours flying time. Including the planning and after-action activities, total time approximates to 5,000 hours of at-the-job experience. Aircrew members achieved proficiency after their first assignment, and higher levels of proficiency after their second assignment (or after weapons school). This contrasts with the current situation. Fewer flying hours are available (due to expense), so there is the pressure of getting experience with less practice time. And there is the staffing pressure. In this case, since there is significant functional overlap of the B-52 and the B-1, transfer is rapid. Thus, the individual in this example career was told he would be an instructor immediately after taking his B-1 qualifying examination.

In the example career, there was a hiatus during the B-1 assignment. That hiatus required the requalification, including 15 practice flights.

> *"Then after two sorties I felt back up to speed. I was at least as proficient as the others…. [but] stuff that had changed in the B-1 was what took longer/most time to (re)acquire. For software*

> *especially for new weapons I will have an instructor brief me and*
> *take me out on my first sortie, tell me the buttonology."*

This comment has clear implications for the content of training given during hiatus periods.

Based on these and other career case studies discussed at the Working meeting, we can list some ironies and paradoxes of learning, training and careers that complicate any effort toward acceleration of proficiency and the facilitation of retention. These are described in Tables 4.2 and 4.3.

Table 4.2. Paradoxes and ironies of learning that complicate the acceleration effort.

Paradox of Domain Specificity	High proficiency is domain and sub-domain specific. Generalization about transfer of either knowledge or skill is always tentative. On the other hand, expertise is defined by experience at coping with diverse situations that stretch the competence envelope, so there must be transfer.
The Envisioned World Paradox	Changing world circumstances entail entirely new forms of work. The need for integrated operations (airs, space, and cyber) is apparent, and the need for a workforce at the highest levels of proficiency is urgent. But cross-domain integrated training is not realistic. There is too much to train, in too little time. The pace of adaption and updating of instruction cannot keep pace with the change in the work. One cannot plan in advance for training needs or for retraining needs.
The Moving Target Paradox	Also, as technology changes, as assignments change, and as jobs change, the cognitive work changes. Learning and re-learning on the job must be continuous. But there is too much to train, in too little time. Thus, the pressure is to do "just-in-time training," but such training is at odds with notions of proficiency training.
Paradox of Feedback	You need to provide rich, informative feedback about both outcome and process, but feedback can forestall the learner's own drive to achieve understanding by thinking about past performance. Some kinds of immediate feedback help, some don't some kinds of delayed feedback help, some don't.
The Skills-Capacities Paradox	Analysis of jobs by skill (task analysis) generates process descriptions that can be used in training and can be used as prescriptions or roadmaps for work conducted in the operational context, but will be brittle due to "moving target" phenomena. Analysis of jobs by capacity (e.g., sensemaking, coordinating, planning, etc.) is more appropriate for the analysis of complex cognitive work systems but feeds into training only on the assumption that instruction in "critical thinking" will transfer.
Paradox of Tough Tasks	Achievement of high levels of proficiency stems from extensive and motivated practice at difficult or tough cases. But case difficulty is closely tied to novelty or "lying at the fringes of the ordinary," and thus the learning would be to some extent case specific. Thus, it might not promote transfer though the "tough tasks" assumption implies that it does.
The Paradox of Failure	Different things are learned in different ways by individuals at different levels of proficiency. If a trainee fails or errs when working on a scenario, the learning will likely be about how to avoid that particular error and will be to some extent unique to the exercise. But journeymen, senior journeymen, and experts learn more from their mistakes than their correct actions/decisions.
The Irony of Evaluation	Evaluation should be a learning experience, and yet this aspect of performance or knowledge evaluation is generally not leveraged as useful feedback.

Another problem that was noted in the Working Meeting was the ambiguity of some core concepts and the linkage of these to deeper philosophical and methodological issues. Training, transfer, proficiency must all be thought of in terms of types of knowledge (declarative, procedural, tacit, intuitive, etc.). In some circumstances these distinctions are useful (e.g., the generalization that well-learned skills decay less than declarative knowledge) but in other circumstances they are not (e.g., the problem of operationally defining intuition).

An example discussed at the Working Meeting was the concept of a "task." Research by Alice Healy and her colleagues (see Healy, 2007) had college student participants learn a time estimation task (estimating the durations of temporal intervals) and simultaneously attempt to recite the alphabet backwards. After learning to a level of minimal proficiency, the secondary task was changed. Participants resultantly performed worse at the primary task. So, when they were learning the dual tasks (the experimenter's perspective) were they not just learning a single "task" (the participant's perspective)? Now consider the notion of task with regard to complex sociotechnical systems. Cognitive work is the context-sensitive, knowledge-driven choice among alternative activities. It often appears as if workers are conducting tasks, but that is in routine situations for stable task goals. A "task," in the traditional human factors sense, is a sequence of specifiable activities that will achieve some particular goal. Such task analyses can be used prescriptively, and can be used in training. But it is not judicious to take this as the single model for founding a theory of instruction for complex cognitive work.

A specific example of how the traditional concept of "task" may be an impediment to advances in research and theory is that it reinforces an artificial notion of separability. Complex cognitive work can always be analyzed into component goals and those goals mapped onto activities and sometimes onto step-wise procedures. But those activities are more often parallel and integral (a single activity contributes to the achievement of more than one goal) and are sometimes in conflict even when they are integral (a single activity contributes to one goal but at the expense of another).

An example might help. A weather forecaster is examining upper air charts radar to look for signs of instability. This is a "primary task" in that it has a specifiable goal and describable activities associated with achieving it. While looking at the upper air charts, the forecaster can also examine a Doppler radar image to look for indicators of whether advection is occurring. This too is a "task" in that it has a specifiable goal and describable activities associated with achieving it. While examining the radar the forecaster is sensemaking with reference to his mental model based on inspection of the upper air data. For the forecaster, the real task is to understand the atmospheric dynamics and project them into the future. It is a distortion to express in the psychologist's language of tasks ("Look here to find this cue, look there to find that cue, etc.").

The traditional notion of task reinforces the view that in some complex activity there is a "primary" task and one or more "secondary tasks." Such analysis makes for comfortable experimental design in the academic laboratory. It makes for a comfortable decomposition into sequences. But it is of limited applicability to complex cognitive work. Which task counts as the primary one and which as the secondary ones varies over time and depends on circumstance and the unfolding of events.

Therefore, one should question the wording of the functional task principle when applied to accelerating proficiency. By the principle, secondary task requirements are often integrated with primary task requirements during learning, resulting in the acquisition of a single functional task rather than two separate tasks (Healy, et al., 2005; Hsiao & Reber, 2001). As the forecasting example suggests, primary and secondary tasks are always integrated, so much so that the primary-secondary distinction loses its value. The concept of the "extraneous" task definitely loses its value. Certainly, if some job involves some principle task ("primary" goals) and additional tasks not deemed of surmount importance ("secondary" goals), it nonetheless is necessary to train in all the tasks and do so in a way that realistically integrates rather than separates them. In short: If in the actual job the worker has to do two things at once, then training should involve doing two things at once. What counts as a "task" depends entirely on the perspective (experimenter/job analyst versus the worker).

Table 4.3. Paradoxes and ironies of careers that complicate the development of proficiency.

The Policy-Proficiency Paradox	In some domains (e.g., intelligence analysis, cultural understanding, others) broad knowledge is a requirement. Promotion to leadership positions depends on having had experience in diverse jobs/roles. But this policy limits the opportunity for individuals to achieve high levels of proficiency in any one job/role.
The Culture-Measurement Clash	Fighter piloting entails the issue of measuring performance gains after the achievement of ceiling-level performance. Research has shown that experts continue to get better even after they "always get it right" on some criteria measure of performance. Once a pilot has achieved very good performance as evaluated at some stage of training or operational performance, they will maintain that level, on the record, because if they do not they will not advance in their military career. This suggests that in some domains or organizations there might actually be incentives against measuring (and thereby understanding) proficiency and its development.
The Myth of the Career Path	Careers are not pathed in the sense of tracking a standardized progression plan. *"While there is a written path, it is rarely followed."* Careers are managed within sets of changing constraints, especially "bellybutton shortages." In some specialties (e.g., piloting) there is a sophisticated process for managing careers. In most specialties there is not. *"You can select your preferences for future assignments, but your commander also makes recommendations and then the personnel office decides, depending on needs, billets available, etc."* In some specialties, time out of career field is not tracked so you do not know when to add reintegration training.
The Irony of Transitioning	Promotion hinges on broad experience, to develop competency at jobs/roles that fall at supervisory levels. But assignments (in the military) will transition individuals across levels. Just in time training courses are out there, but are not designed for people transitioning across levels. Training is necessary prior to any reassignment, and while the courses (typically 2 months long) can be good for exposure they do not promote deep comprehension. There is not enough time available. There is no tracking of people who can help in training. It can be awkward to ask for help form subordinates.

Table continues

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The Ironies of Demotivation	Demotivation manifests in a number of forms and for a variety of reasons. Deployment itself contributes to the acceleration of proficiency, but the basic job responsibilities can consume one's time and energy. There is significant burn out potential by doing extra learning and training. Broadening negatively impacts career progression and triggers thoughts of getting out. "*You repeatedly experience a loss of confidence.*"
The Ironies of Reassignment	Reassigning an individual just as they achieve high proficiency cuts against the notion that organizational capability is built upon individual expertise. Reassignment may be necessary for staffing, and is necessary for training individuals who are selected to move to higher levels of work. But it can be recognized that reassignment is at least partly responsible for creating the problem of skill decay in the first place. There are significant secondary effects that also should be considered. For example, upon return to a primary assignment the post-hiatus refresher training might involve work on routine cases. This may lead to overconfidence in the earliest stage of a redeployment, and might limit the worker's ability to cope with novel or challenging situations.
The Ironies of Under-utilization of Resources	While some organizations recognize the need to collect and share "lessons learned," such lessons are often archived in ways that make meaningful search difficult, and hence become "lessons forgotten" Debriefing records are a significantly under-utilized resource for training, and could be formative of a library of cases, lessons learned, and scenarios for use in training.
The Irony of the Consequences of Limiting the Resources	In past years, re-training following hiatus could be brief (6 weeks) (we might say "accelerated") because pilots had had thousands of hours of flying time prior to their hiatus. But pilots are flying less now, largely due to high cost. This has two repercussions: It mandates more training post hiatus (which has its own associated costs) and the reduced flight practice hours detract from the goal of accelerating the achievement of proficiency, thus placing the overall organizational capability at risk.

4.3 Research Challenges

Much of the Working Meeting discussion can be integrated under this theme, with particular topics being:
- o Forging the Right Theory
- o Finding the Right Training and Mentoring Methods
- o Finding Methods and Designs for Acceleration Research

4.3.1 Forging the Right Theory

Given the complexity of many domains, accelerating the development of proficiency cuts across processes, ranging from perception and memory to category learning, problem solving, and decision making. As such, any viable research program needs to put forth a theoretical approach

that can encompass a wide range of cognition (see Roediger, Gallo, & Geraci, 2002). There appears to be some significant degree of consensus concerning the important theoretical notions to scaffold our understanding of the achievement of proficiency. Before expressing that consensus we must point out a topic of discussion at the Working Meeting on which there was not a consensus.

Cognitive Load Theory asserts that there are different kinds of mental workload (Cooper, 1998; Paas, Renkl, & Sweller, 2003; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005). Intrinsic cognitive load depends on the complexity and interactivity of the materials or tasks that must be learned. Intrinsic cognitive load is the difficulty associated with the problem type and cannot be altered by an instructor. Extraneous cognitive load is caused by activities during learning that are unnecessary and so interfere with schema acquisition and automatization. Extraneous cognitive load is created by the manner in which information is presented to learners, attributed to the design of the instructional materials. This is under the control of instructors and instructional designers. Germane cognitive load is workload to achieve the goals of the task. Germane activities are beneficial for the advancement of proficiency. Germane cognitive is that load devoted to the processing, construction and "automatization" of schemata—a mixture of phenomena which we might interpret as the effort required to form a mental model. How this differs substantively from intrinsic cognitive load is a matter of debate.

The way this translates from the academic context to the more practical context of proficiency acceleration is not clear, in part because the distinctions are not entirely clear. The purported value of these distinctions is guidance in the analysis of cognitive work. The literal claim is that intrinsic load is immutable but instructional designers can manipulate extraneous and germane load. It is suggested that they limit extraneous load and promote germane load. In other words, instructional processes should minimize extraneous cognitive load and optimize germane cognitive load. That might seem like a homily with which no one could disagree, but is it judicious in practice? Actual work in complex cognitive work systems is typified by distractions, the need for kluges, and the need for work-arounds (Koopman & Hoffman, 2003). If training does not prepare workers for that "extrinsic" mental workload, and focuses solely on preparation to engage in the activities that contribute directly to the achievement of the primary task goals, then the training will not adequately prepare workers for "the real world." In other words, there will be a boundary condition imposed on transfer.

Turning now to the consensus, it is agreed that Recognition-Primed Decision making is a phenomenon that typifies expertise, in diverse domains. It is agreed that a core phenomenon of proficiency is the ability to apprehend complex dynamic patterns.

All of the pertinent theories are essentially sets of assertions or postulates. From the standpoint of formal philosophy of science, they often lack metatheoretical and ontological assertions and assertions about methodology. Hence, they should be thought of not as theories, but as sets of hypotheses and postulates about concepts, and one can be at liberty to combine or merge their proposition sets, as we do in the following discussion.

It is also agreed that the theoretical foundations for accelerated proficiency will include notions from Cognitive Flexibility Theory (CFT) (Spiro, 1988, 1992) and Cognitive Transformation

Theory (CTT) (Klein & Baxter, 2009). Each of these theories presents as a set of hypotheses, and these can be readily integrated. The key ideas of each of these theories are presented in Tables 4.4 and 4.5.

Table 4.4. Key ideas of Cognitive Flexibility Theory.

CORE SYLLOGISM
1. Learning is the active construction of knowledge. 2. Learning entails reductive explanation. 3. Reductive explanation reinforces and preserves itself through misconception networks and through knowledge shields. 4. Advanced learning is the ability to flexibly apply knowledge. *Therefore,* instruction by incremental complexification will not be conducive of advanced learning. *Therefore,* advanced learning is promoted by emphasizing multiple interconnectedness of cases and concepts along multiple conceptual dimensions, and the use of multiple representations.
EMPIRICAL GROUND AND CLAIMS
Studies of learning of topics having conceptual complexity (medical students).
Demonstrations of knowledge shields and the dimensions of difficulty.
Demonstrations that learners tend to oversimplify (reductive bias) by the spurious reduction of complexity.
Studies of the value of using multiple analogies.
Learners tend to rely too much on generic abstractions, which leads to failure to transfer knowledge to new cases.
Learners tend to regularize that which is irregular, which leads to failure to transfer knowledge to new cases.
Learners tend to de-contextualize concepts, which leads to failure to transfer knowledge to new cases.
Learners take the role of passive recipient versus active participants.
Conceptual complexity and case-to-case irregularity pose problems for traditional theories and modes of instruction.
Instruction that simplifies (the incremental complexification approach) can detract from advanced knowledge acquisition by facilitating the formation of reductive understanding and knowledge shields.
Instruction that emphasizes recall memory will not contribute to inferential understanding and advanced knowledge acquisition (transfer).
ADDITIONAL PROPOSITIONS IN THE THEORY
Advanced knowledge acquisition (apprentice-journeyman-expert) depends on ability to achieve deeper understanding and apply it flexibly.
Barriers to advanced learning include complexity, interactions, context-dependency, and ill-structuredness (inconsistent patterns of concepts-in-combination).
Active "assembly of knowledge" from different conceptual and case sources is more important in learning (for domains of complexity and ill-structuredness) that retrieval of knowledge structures.

Table continues

Table continued

Misconceptions compound into networks of misconceptions. Misconcepts of fundamental concepts can cohere in systematic ways, making each misconcept easier to believe.
Representations with high interconnectedness will tend to serve as "misconception-disabling correct knowledge."
Cognitive flexibility is the ability to mobilize potential knowledge, small, pre-compiled knowledge structures ("adaptive schema assembly").
Cognitive flexibility is the ability to represent knowledge from different conceptual and case perspectives and construct from those a knowledge ensemble tailored to the needs of the problem at hand.

The emphasis of CFT on overcoming simplifying mental models advises against applying instructional methods that involve progressive compexification. As is true for all methods, whether incremental complexificatiuon works or not depends upon how it is conducted (Reigeluth, personal communication). A traditional learning hierarchy approach that compartmentalizes material and assumes fixed tasks (e.g., Gagne, 1968) can detract from advanced knowledge acquisition because the decomposition limits opportunities to learn about interactions. The Simplifying Conditions Method (Kim & Reigeluth, 1996; Reigeluth, 1999) provides an approach to incremental complexification that is ideally suited to advanced knowledge acquisition because it incrementally introduces interactions as well as "compartments" of to-be-learned material.

Table 4.5. Key ideas of Cognitive Transformation Theory.

CORE SYLLOGISM
1. Learning consists of the elaboration and replacement of mental models. 2. Mental models are limited and include knowledge shields. 3. Knowledge shields lead to wrong diagnoses and enable the discounting of evidence. *Therefore* learning must also involve unlearning.
EMPIRICAL GROUND AND CLAIMS
Science as sensemaking.
Flawed "storehouse" memory metaphor and the teaching philosophy it entailed (memorization of facts; practice plus immediate feedback, outcome feedback.)
Studies of science learning show how misconceptions lead to error.
Studies of scientist and student reactions to anomalous data.
Success of "cognitive conflict" methods at producing conceptual change.
ADDITIONAL PROPOSITIONS IN THE THEORY
Mental models are reductive and therefore incomplete and flawed.
Learning is the refinement of mental models.
Experts have more detailed and more sophisticated mental models than novices. Experts have more accurate causal mental models.
Flawed mental models are barriers to learning (knowledge shields).
Learning is by sensemaking (discovery, reflection) as well as by teaching.
Refinement of mental models entails at least some un-learning (accommodation; restructuring, changes to core concepts).
Refinement of mental models can take the form of increased sophistication of a flawed model, making it easier for the learner to explain away inconsistencies or anomalous data.
Learning is discontinuous. (Advancing when flawed mental models are replaced, stable when a model is refined and gets harder to disconfirm.)
People have a variety of fragmentary mental models. "Central" mental models are causal stories.

The merger of CFT and CTT would be a key part of the theoretical foundations for acceleration research. Problems that involve dynamics, interacting processes, nonlinear causation, simultaneous events, and other features are particularly difficult for learners. When confronted with the gaps and inaccuracies in their knowledge or reasoning, the learners are likely to invoke a "knowledge shield" that allows them to preserve their simplistic understanding in the face of contradictory evidence (Feltovich, et al., 2001). This links to the core concepts of CTT (Klein & Baxter, 2006), which developed from research in the field of Expertise Studies. CTT argues for the importance of "unlearning"—for experiences that force people to lose faith in their entrenched, simplistic mental models so that they can move to deeper levels of understanding.

CFT suggests that for expertise acceleration, feedback must help the learner transcend their inclination to invoke a knowledge shield, and CTT suggests that feedback must help the learner un-learn concepts or notions that incorrectly simplify their understanding of the domain. It is widely believed that people learn more from their mistakes than from what they get right. When

everything works the way it is supposed to, one is less likely to receive feedback about what did not work or what might have been done better. Experts seek out corrective feedback, feedback pointing out targets for improvement. It has been said that apprentices make the same mistake twice, journeyman make the same mistake once and experts work until they never make mistakes. While this is a point well taken, domain specialists who are intrinsically motivated often seek out corrective feedback that allows them to perceive their errors. Sonnentag (2000) showed that the more experienced problem solvers (domain of software engineering) sought out corrective feedback from coworkers.

Cognitive Transformation Theory emphasizes the paradoxical fact that the better the mental model, the harder it is to move past it because the model does a better a job and is easier to protect using knowledge shields to explain away contrary data. Some workers stagnate as their performance asymptotes because they are so effective in defending flawed mental models. Cognitive Transformation Theory argues for the importance of "unlearning" – experiences that force people to lose faith in their mental models so that they can move to the next level.

The implication is that high levels of proficiency are achieved when the practitioner has an ability to lose confidence in an existing mental model.

CFT and CTT each try to achieve growth but in different ways. For CFT it is flexibility and for CTT it is a better mental model, but one that will have to be thrown out later on. CFT does not say what the sweet spot is for flexibility. It just pushes for more flexibility. If you over complexify you do not get any traction and can get paralyzed. It thus might be considered a "lopsided" theory, or at least an incomplete one. Humans are very flexible but need structure in order to gain momentum. To use the analogy of the movement of a snake, if it were completely flexible it could not move.

The two theories have slightly different focus. The two theories have similar core syllogisms. Both depend on the notions of mental model formation and knowledge shields. They both tap into the same general empirical base about the phenomena of proficiency, expertise, and high-end learning. Although the premises of CTT seem more general and encompassing than those in the core syllogism of CFT, CFT has academic and scientific precedent.

Taken separately, they are incomplete in the sense that they tap primarily into different sets of phenomena. Thus, if merged they might form a more complete theory. The two theories are certainly compatible and we find no outright contradictions in comparing their propositions. Given that they point to complementary ideas and implications about training, it would seem practical to merge them.

The core syllogism of the merged theory would be the following:

1. Learning is the active construction of knowledge, the elaboration and replacement of mental models or causal stories.
2. Learning entails reductive explanation.
3. Mental models are limited. People have a variety of fragmentary mental models.
4. Reductive explanation reinforces and preserves itself through misconception networks and through knowledge shields.
5. Knowledge shields lead to wrong diagnoses and enable the discounting of evidence.

Therefore learning must also involve unlearning and relearning.

Therefore, advanced learning is promoted by emphasizing multiple interconnectedness of cases and concepts along multiple conceptual dimensions, and the use of multiple representations.

CFT emphasizes the achievement of flexibility whereas CTT emphasizes the need for unlearning and re-learning. Both theories regard advanced learning as a form of sensemaking (discovery, reflection) and both regard learning as discontinuous; advancing when flawed mental models are replaced, stable when a model is refined and gets harder to disconfirm.

Both theories assert that certain forms of training are not appropriate for advanced learning— instruction via compartmentalized knowledge, clear instances, and reproductive memory tasks will not promote advanced learning. Learning at beginning and intermediate levels can certainly benefit from this form of instruction. Anderson's ACT-R proposes that automatization of lower-level learning facilitates subsequent higher-level learning (Anderson, 1996; Anderson, et al., 2004). But for advanced learning, simplification methods can be counterproductive.

Both CFT and CTT theories caution against the use of extrinsic immediate outcome feedback for advanced learning because at advanced levels immediate extrinsic feedback can prevent skill development and reduce transfer. At the same time, both theories are based on the observation that continuous outcome monitoring—*intrinsic* immediate outcome feedback—is be critical.

Both CFT and CTT theories note the value of mentoring, i.e., active learning plus opportunistic guidance. Table 4.6 presents a set of propositions concerning training that is generated by a merger of theories. These prescriptions should be understood in light of the fact that "Training for complex tasks is itself a complex task, and most principles for good instruction are contextual, not universal" (Reigeluth, personal communication).

Table 4.6 Implications of the merged Flexibility/Transformation theory for training and instructional design.

THE GOOD MENTOR
Uses a modeling approach where appropriate actions and decisions are illustrated in the context of the actual operational environment, and, when warranted, the learner is guided in his/her own performance.
Provides support for management of increased uncertainty and cognitive load when the student is dealing with complexity.
Provides trainees at junior proficiency levels with particular help in forming their initial mental models, e.g., by promoting information seeking strategies.
Is able to discern the trainee's mental model and diagnose of the reason for the trainee's poor performance. From this, the mentor can predict when and why the learner will form a simplistic or inaccurate understanding.
Is able to craft cases or problems that deliberately push the trainee to the next level of understanding or reasoning skill.
Presents scenarios that encourage rethinking of concepts and mental models by triggering a cognitive conflict in which some baffling event or anomaly triggers a loss of faith.
GOOD INSTRUCTION
Presents content knowledge and case material using multiple representations, especially for ill-structured problems or domains.
Presents practice opportunities in environments that replicate the operational environment to the greatest extent feasible.
Involves analysis of individual cases at different times, in different contexts, for different purposes, using multiple representation, and from different perspectives is essential for advanced knowledge acquisition.
The apprentice works with the mentor to solve problems, while also making explicit the strategies being adopted as well as the apprentice's knowledge and reasoning.
Covers content more than once to insure learning of case complexity, conceptual complexity and context-dependent variability.
Uses feedback that informs the trainee of what to do differently (process feedback versus outcome feedback).
Scaffolds the trainee to engage in sensemaking and thereby generate their own feedback.
Scaffolds the trainee in going from recognition of a flawed mental model by making a richer model.
Involves instruction and practice in handing ill-structured problems, that is, problems in which goals are unclear or morph.
Instructs in variability using extreme cases, and non-routine cases illustrating context-dependence of concepts and patterns. (With the caution that the use of extreme cases can be counterproductive at intermediate stages of learning.)
Emphasizes multiple interconnectedness of cases and concepts along multiple conceptual dimensions.

While useful, CFT and CTT do not address all aspects of learning, and not even all aspects of learning of complex tasks. An even more expansive view is needed for designing training based on incremental complexification of tasks, and identifying "desirable difficulties" as a function of domain and learning level. For example, the Simplifying Conditions Method (Reigeluth, 1999) can be explored for determining perceived difficulty of cases for and sequencing them appropriately. It will be necessary to explore, for each domain, the context-dependence of most methods for fostering learning, as a function of instructional level, especially the requisite levels of fidelity and authenticity.

4.3.2. Finding the Right Training and Mentoring Methods

Discussions at the Working Meeting of training methods focused on feedback, retention, transfer, and mentoring.

Feedback

With regard to feedback, we know of the substantively different kinds (outcome, process, immediate, delayed, etc.) but cannot make broad generalizations. Feedback is not always helpful. It is sometimes helpful in the short-term but not in the log term. And so forth. It may be possible to map feedback regimens onto skills/tasks at least to some extent. Thus, for example, jobs/tasks that involve difficult critical thinking and sensemaking might benefit from delayed process feedback. Using the Pareto Principle it would be possible to possible to formulate guidance in the use of feedback

- Remembering Reigeluth's cautionary tale that "Training for complex tasks is itself a complex task, and most principles for good instruction are contextual, not universal," training would certainly benefit from a more extensive empirical base to guide the integration of different types of feedback into instruction at different levels.

Retention and Decay

We know about the general course of forgetting, ranging from minutes (lab science) to years, and for various sorts of learning materials. There is consensus on the claim that the level of proficiency or overlearning achieved during initial acquisition is the best predictor of skill decay. With regard to skill decay and "types" of knowledge, some assert that declarative knowledge is less often forgotten and procedural knowledge is more often forgotten; whereas others assert that procedural knowledge, once overlearned, is highly resistant to decay, as in riding a bicycle. Healy's Procedural Reinstatement Principle (2007) is based on the premise that procedural knowledge (i.e., skill) is more durable than declarative knowledge.

Decay differs for different tasks. Currently, decisions about retraining are often made by negotiation. So in piloting, for instance, a hiatus of some length might be traditionally mapped onto a retraining course of 20 sorties, but there may only be funding for 10, so a compromise of 15 is achieved by negotiation.

- We currently have no useful empirical base about individual difference predictors of retention, such as age, gender, cognitive ability level, education level, etc.
- We currently have no useful empirical base about how periodic booster sessions (number, spacing) affect learning and forgetting rates.
- We currently have no useful empirical base that informs about differential decay of particular skills. Booster training should focus on refresh of skills that would ordinarily show faster drop-off.

An important aspect of retention of skill is that following hiatus the work will have changed. Retention is not simply gaining back skills but adapting to new world. Thus, re-learning must be an integral part of post-hiatus training or refresher instruction.

The issues and challenges in the military of skill decay due to hiatus assignments, are by no means unique to the military. The example was given of corporate practice. CEOs and senior managers get cut off from experiences that keep them fresh, and then they make bad decisions. Steve Jobs is a counter-example, we might say, illustrating accelerated updating more than accelerated learning since people aren't learning from scratch. Some notion of "accelerated updating" should be added to the list of kinds or definitions of acceleration.

The opportunity and need is to actually track changes in job requirements longitudinally in one or more selected domains where there is a rapidly changing job environment (e.g., technology adoption issues). This would be especially pertinent with regard to the aging civilian population. It might be possible, and would certainly be useful, to developing measures of motivation that might predict attrition.

- We currently have no useful empirical base about adaptation retraining.
- We currently have no useful empirical base about differential decay of "types" of knowledge or skill in the context of complex work in professional domains, on the assumption that transfer is either between problem types or between sub-domains within the broader domain.

We have presented the generalization that decay is less for skill learning than knowledge learning. The fuller generalization is that for skill learning, retention is strong but transfer is limited, whereas for fact learning, retention is poor but transfer is robust. This leads directly to the topic of transfer.

Transfer

Principles of transfer from academic/educational research provide some guidance, but simultaneously point to gaps in our empirical base. This is detailed in Table 4.7. (This does not include the "functional task principle," for reasons explained above in section 4.2.)

Table 4.7 Principles of training and transfer from academic/educational research and opportunities for empirical research.

PRINCIPLE	OPPORTUNITIES
Specificity of Training Principle For optimal performance, the entire configuration of task requirements during training needs to match those in the field as closely as practically possible. Retention and transfer are reduced when conditions of learning differ from those during subsequent testing (Healy, et al., 2006).	This principle has in many cases already been mapped onto training programs. It likely applies broadly to skills, knowledge and the achievement of proficiency.
Contextual Interference Principle Interference during learning facilitates later retention and transfer (Battig, 1979; Schneider, et al., 1995).	Determining domain or content-appropriate specification on what counts as "interference."
Training Difficulty Principle Any condition that causes a desirable difficulty during learning facilitates later retention and transfer (Bjork, 1994; McDaniel & Einstein, 2005; Schneider, et al., 2002).	Determining domain or content-appropriate specification on what counts as "desirable difficulty."
Procedural Reinstatement Principle Specificity (limited transfer) occurs for tasks based primarily on procedural knowledge (i.e., skill) whereas generality (robust transfer) occurs for tasks based primarily on declarative information, or facts.	Determining sensible distinctions on "types" of knowledge, as appropriate to individual domains. Confirming the reinstatement effect for professional domains.

With the exception of the Specificity of Training Principle (as noted above in the left-hand column of Table 4.7), the generalizability of these principles—carrying them over from academic/educational research into domains of professional proficiency and complex cognitive work—is not at all clear. A principle reason is related to the relative simplicity of laboratory tasks and the relative complexity of work domains. Training and transfer contexts in academic/educational research are highly similar and what is changed is one or more details of individual, isolatable tasks. In the work domain context, what is the transfer from and what is it to?

Transfer is traditionally thought of in terms of gains (or losses) in performance that is easily measured (e.g., correct responses or accuracy over time) on isolated fixed tasks (historically, typing, pursuit rotor, etc.). This concept is of limited use in the analysis of complex domains, complex dynamic jobs, and complex cognitive work. Researchers today speak of notions such as "deep learning" of concepts, and the ability to make meaningful connections between previous learning and novel situations. The study of transfer, and especially applications to the analysis or complex work domains, needs to break out from this tradition of transfer of fixed skill or fixed knowledge.

One would not expect an expert at urban firefighting to have all the reasoning capabilities of a firefighter experienced in wildland fires. Yet, both are firefighters and they engage in many of the same "tasks." One would not expect an expert at forecasting severe storms in the

southeastern US to be competent at predicting severe weather in the Canadian Rockies, though both involve the same data types, the same principles of atmospheric dynamics, and so forth. So, the issue is, what are the bounds?

What this discussion shows is that generalizations about transfer are difficult to make, and the default assumption is that knowledge and skill do not transfer (i.e., expertise is highly domain-specific). On the other hand, there is the paradox of domain specificity (Table 4.2, above) (Expertise is defined by experience at coping with diverse situations that stretch the competence envelope, so there must be transfer.)

What is needed is a conceptual designation other than the word "transfer" to capture the phenomenon at hand. "Transposition" might be an appropriate term. The skill or knowledge or capacity that is learned in one application but subsequently utilized in some other context is not adapted or mapped literally. Rather, it undergoes some sort of modification or transformation or realignment.

For application to cognitive work and complex domains, the assumption must be that transfer of capability (competence and proficiency) is desired when the transfer is from one problem type to some other substantively different problem type within a single sub-domain, or when the transfer is between problems in different subdomains.

With regard to transfer, we do not have a useful empirical base about job requirement changes and transfer of skills within careers (e.g., piloting a jet versus a UAV; Air Traffic Control with changing technology) and knowledge obsolescence in jobs and what motivates people to engage in the type of deliberate practice needed to maintain and develop skill. As one Working Meeting participant put it,

> *"The issue is transfer of what to what. We need to define all the variables or dimensions in the transfer. We need operational definitions so that we can measure. It is really tough nut to crack."*

Mentoring

A number of Working Meeting participants discussed issues and empirical gaps on topics of mentoring.

We may not be giving learners the best opportunity to become experts if we don't also train mentors and experts in helping that person learn. It seems like many mentorship programs rely on a "watch and learn" mentality where the deeper knowledge of the mentor may not be obvious. Shared experience is that experts do not necessarily make good mentors. The most experienced and knowledgeable workers, who are regarded as experts because they make the job look easy, often do a terrible job of describing what it is they do and know. Thus there has emerged the concept of the "expert mentor." While we have some ideas of what makes for a good mentor (see Table 4.6, above),

- We currently have no useful empirical base on how to identify individuals who would or could become good mentors.
- We currently have no useful empirical base on how to teach people how to be mentors.

- We currently have no useful empirical base on specific mentoring techniques and tools that mentors can use to share their expertise with mentees.
- We currently have no useful empirical base on such factors as cost-benefits of mentoring, the impact of organizational culture, effects of extrinsic motivation (e.g., rewards) for mentoring, etc. (Should mentors be rewarded based on how well their mentees perform?)
- Do we reward / recognize people for the mentoring aspects of their work? That is, do we reward them based on how well their mentees perform?

While there is some empirical evidence that engaging trainees who are relatively more advanced in the tutoring of trainees who are relatively less advanced, the positive findings in academic/educational research have no counterpart in studies of "real world" job contexts. Is there value in teaching novices how to be mentors? Nor do we have a handle on the effects of tutoring on the tutors. Specifically, what is the benefit of practicing trainees from the very start in how to describe the skills they are learning (knowledge sharing skills) at the same time that they are practicing the skills in which they will become experts?

Final Comment

It was noted a number of times in the Working Meeting that many of the notions that were presented and discussed entail a decomposition of domains, jobs, and tasks. The ideal would be a decomposition in terms of competencies that can be mapped on to decay rates and thence onto retraining plans. Decomposition would be with respect to types of learning required, adaptation to different learning styles, and so forth. There are certainly significant theoretical and methodological issues with such a traditional human factors approach. As has been mentioned, the notion of a "task" has limited utility and applicability in the analysis of complex cognitive work. If one takes an alternative approach of analysis in terms of the primary macrocognitive functions, one is left with a roster of very high-level capacities (e.g., sensemaking, resilience, mental model formation, etc.) that cannot easily be mapped onto instructional designs. Domains and jobs are certainly multidimensional (not to mention that they are moving targets). This presents a significant conceptual and methodological challenge:

- We currently have no useful empirical base on alternative schemes for mapping of domains with respect to (re)training.

4.3.3 Methods and Designs for Studying Acceleration

In this Section, which summarizes the Working Meeting, we note only the most salient ideas that were raised about acceleration methods, experimental designs, and research plans. The full integration of ideas and recommendations concerning acceleration is presented in Section 6 of this Report, merging ideas about acceleration from the literature review and the Working Meeting.

Acceleration

Ideas presented at the working Meeting pointed to each of the four main meanings of "accelerated proficiency" that were presented in Section 1, above: *Rapidizided Training, Rapidized Knowledge Sharing, Accelerated Proficiency,* and *Facilitated Retention*. A nuance on

Facilitated Retention emerged at the Working Meeting, that of "Accelerated Updating." This is the notion that hiatus maintenance training and post-maintenance Refreshing should focus on aspects of the work that have changed during the hiatus. This notion is predicated on the "moving target" principle that governs sociotechnical workplaces.

Some of the suggestions for acceleration methods cut across these kinds of acceleration. For example, achieving accelerated proficiency by better training of the trainers relates to ideas of accelerated proficiency and also rapidized training (i.e., improved mentoring).

"Just-In-Time" training (JIT) was raised as an example of accelerated learning. The assumption of JIT is that if just enough information can be provided quickly, in the work setting, that this would make it possible to preserve the capability of the work system. While JIT is a form of on-the-job training, the intent is to cope with rapid change. In JIT, short slices of instruction (< 5 minutes) are targeted to just one or a few concepts or processes. Different from classroom instruction, the JIT material can be delivered online, and can use enriching multimedia such as video with narration. JIT as defined depends on some methods for Just-in-Time Assessment, allowing training managers to rapidly estimate what the trainee has learned or what skills have been acquired.

One view is that JIT is necessary because of the paradox of limited time in the schoolhouse versus the constantly changing nature of work (see Section 4.2, above). But the concern expressed at the Working Meeting is that JIT cuts against what is known about the development of proficiency, and learning in general. Specifically, the acquisition of proficiency depends on practice, practice, and more practice. On this view, just-in-time training is a recipe for just-in-time disaster especially since proficiency may be most urgently needed in pressing circumstances.

Scenario-Based Training

A main theme at the Working Meeting was training and accelerated learning by means of cases or scenarios. This notion is entailed by the law of frequency, the principle of domain specificity, and is supported by both research and practical experience. Several aspects of the development of proficiency (discrimination, transfer, progressive, tacit knowledge. etc.) point to the use of multiple scenarios or cases in training. These would be sequenced, according to the notion of "increasingly complex microworlds" (Burton, Brown, & Fischer, 1984; Bunderson, 2006). Both contrast and repetition effects are possible even by changing only a few problem variables of interest.

Exemplars of successful acceleration are Top Gun, the National Training Center, and the Think Like a Commander Program. Shared characteristics of these programs are presented in Table 4.8.

Table 4.8 Characteristics of effective scenario-based training.

- The scenarios are tailored to learners (individual and/or group), depending on level of achievement, preparedness, or other factors.

- Scenarios are created from lessons learned.

- Scenarios are created based on empirical knowledge on how highly proficient workers apprehend problems.

- Scenario training assumes high intrinsic motivation of the trainee to work hard, on hard problems.

- For any given level of training, the scenarios are tough. They are novel to the learner, challenging them in ways described by Cognitive Flexibility Theory and Cognitive Transformation Theory (see above).

- Typically there is some adversary, such as a superior or more capable opposing agent or force.

- The trainee is challenged to learn to think like the adversary.

- The fidelity is as high as needed. (In order: desktop exercises using paper and pen, virtual worlds presented on computer monitors, virtual environments, very high fidelity simulators, simulated villages.)

- Scenarios mimic the operational context.

- There is a designed-in ability for observers to measure what happened.

- The observers are experts.

- There are multiple reviews, not one single "after action" review.

- Reviews provide outcome and process feedback.

- Reviews include retrospection and the analysis of decision processes, emotional state of mind, teamwork, mental projection to the future, and other macrocognitive processes.

- The goal is for trainees to acquire strategic knowledge, adaptability, and resilience.

We have emphasized simulation-based scenarios, but the training at all levels of proficiency will always use some appropriate mix of training/assessment environments. Much practice, including advanced practice, can be done cost-effectively in a classroom and/or virtual environment. Validation of achieved level of proficiency should ideally be conducted in virtual or near-live environment, in a reliable, valid scenario.

Research Designs, Plans, and Requirements

Certain kinds of studies could commence immediately once domains are selected. Archival research could begin the process of forming a proficiency scale, forming good measures, and building a corpus of cases. One could find a cohort and look back over their record.

There was a consensus at the Working Meeting that a program of research on acceleration should involve the study of at least two interestingly and substantively different domains.

There was a consensus at the Working Meeting that research on acceleration will necessitate the application of proficiency scaling methodology. This includes career analysis, sociometric analysis, and performance testing (see Hoffman, 2010). This methodology is well understood. However, proficiency scales have to be domain-appropriate. Currently, we lack validated proficiency scales for many jobs/tasks.

It was pointed out that we have sophisticated tools for analyzing developmental studies (e.g., longitudinal data sets) such as multi-level modeling techniques and trajectory analysis techniques. At the same time, it was pointed out that the research will have to commence before "good" measures are devised and validated. A primary purpose of measurement is always to improve the measures. Traditional human performance measures will be inadequate for the analysis of complex cognitive work (Hoffman, 2010). In addition, measurement methodology for the study of acceleration will itself have to adapt over the course of the research since the study will be of "moving target" domains.

It would be a major project to develop and compare different training techniques (hands-on, simulation environments of varying fidelity) and conduct longitudinal studies within a population of learners that represent a spectrum of proficiency levels. It would be a major project to conduct such study long enough (more than five years, realistically) to cover hiatus periods over actual careers. Nevertheless, it is precisely such study that would provide the necessary empirical base (see the bullet lists in Section 4.3.2, above).

Rather than tracking a group from an apprenticeship all the way to high proficiency, one can conduct cohort-select designs. There are multiple groups of trainees who represent different levels of current proficiency. Levels could be any or all of: senior apprentice, junior journeyman, journeyman, senior journeyman, junior expert. Once the "grain" is determined, the groups could each be tracked over time.

In addition, a preliminary process of constructing the domain-appropriate proficiency scale, would involve a detailed retrospective analysis of each trainee's experiences and training. Proficiency scaling methodology is reasonably well understood. One would identify individuals who learn fast and slow and conduct retrospective analyses to find out why. One could identify the top performers at each proficiency level (test scores, records of past performance during training) and work backwards to find the success factors. One could study acquisition retrospectively and study degradation and retraining prospectively.

Thus, in such designs one could examine development both retrospectively and prospectively and thereby "cover" more than the five to eight year duration of the actual research project itself. Several capabilities will be needed to support scenario design, beyond access to highly experienced domain practitioners and all the pertinent "lessons learned." Specifically, scenarios may have to be parameterized, so that they can be rapidly or even dynamically constructed. An instructor might introduce "twists" into on-going scenarios to address proximal learning objectives (e.g., triggered by an observation of biased reasoning).

Achieving that will itself require a research program to baseline scenarios for initial assessment against learning objectives and to build a corpus of common and rare scenarios for learning generalized and specialized knowledge and procedures.

Several classes of technology may be central to implementing accelerated learning concepts:

- Pervasive technology for human performance measurement is needed to estimate the effects of training, in the short term, and to validate and calibrate the impact of competencies on task performance, in the long term.

- Scenario engineering technology is required to dynamically adapt training simulations and games in ways that ensure students are continuously stimulated by events that exercise and extend their competencies. In the long term, such technology should help us to assess whether training in specific competencies is feasible in simulations.

- Computational or mathematical models of competency and its impact on performance (e.g., accelerating performance, raising quality) are needed, or will be needed eventually to move from empirical study to model-based design that can support the performance of military organizations under different assumptions about staff composition and size.

The Working Meeting participants recognized that the goal of training—for trainees to acquire strategic knowledge, adaptability, and resilience—and the goal of accelerating that acquisition—are daunting from a scientific point of view. Nevertheless, the consensus was that the research is possible given what is presently known empirically and about methodology. As one Working Meeting participant put it,

> "*Skills proficiency is attained through scenario-based acquisition of the skill to some criterion, more practice after achieving that criterion and then validation of proficiency through assessment of performance. Proficiency can be attained with good training design and situated learning in a short time. Both skill retention and the achievement of higher levels of proficiency are achievable through the same sequence of acquisition, practice, validation though with fewer scenarios needed.*"

5.0 CONCLUSIONS AND RECOMMENDATIONS

In his summary of results from the two Accelerated Learning meetings, Andrews (2009) listed the following key science and technology challenges for accelerated learning:

- Understanding the requirements for high proficiency and how to accelerate its attainment.
- Understanding how to increase retention of high proficiency (facilitated retention).
- Development of serious games that can accelerate the achievement of high proficiency.
- Development of "rapid cognitive task analysis" methods to understand training problems.
- Development of career path methods to facilitate progress along the proficiency continuum and the achievement and retention of high proficiency.
- Calculating the costs and benefits of instituting accelerated learning methods, and the risks of not doing so.

The intent of this section of this Report is to take these ideas a step further by suggesting elements of a roadmap for research on accelerated proficiency and facilitated retention:. Suggestions for acceleration methods include leveraging the important features of practice and mentoring, the technologies of virtual reality training, multi-media for training at complex tasks, and leveraging computer technology to develop libraries of representative and tough tasks and knowledge bases that capture expert knowledge and skill.

5.1. Interdisciplinarity

Research on acceleration, in any of its four senses, will require a multidisciplinary team.

- Researchers who study expertise understand the nature, development, and assessment of proficient performance. They also command methods for the elicitation, representation, archiving, and transmission of knowledge and skill. They understand what it is that the project is trying to accelerate.
- Researchers who conduct large-scale longitudinal studies understand and have experience at tracking learning and skill changes and their components across extended periods of time. They understand the practicalities, measurement issues, and control requirements for such large-scale studies.
- Researchers who study the fundamental processes of learning and memory, in experimental psychology's laboratory studies reveal the main variables that influence the acquisition, retention, and use of knowledge. Methods of controlled study of transfer and flexibility of training are critical in theories of learning, as are issues of memory and skill decay.
- Trainers within an organization are responsible for developing training materials, tracking training effectiveness, etc. They know the current methods of training that are used within an organization, as well as the organization's history and culture regarding training. They have insights into what works for what kinds of skill, why it works, and why it sometimes does not. They have insights into the interaction of training methods, training materials, and the individual capabilities and learning styles of trainees. All these considerations would be critical for the design of attempts at accelerating the achievement of proficiency.

- Human resource specialists have responsibility for writing job descriptions and for creating and conducting evaluation and promotion processes. They have experience with the ways and means by which people are able to gain entry to an organization and the extent to which they subsequently thrive. Any effort at accelerating expertise will require flexibility and creativity in matters of personnel and human resource management.
- Instructional design is a designated work line for creating and certifying instructional materials and methods. Efforts at expertise acceleration will likely need to operate within such an extant organizational context for conducting instruction.
- Researchers who study team cognition understand organizations as systems, for example in their dynamics, interdependence of processes, emergent properties, adaptability, and so forth. Any program of expertise acceleration will need to take place within an existing organizational climate and structure.
- Educational technologists provide tools for selective experience compaction, involving such devices as simulations, games, virtual reality, and other case-based educational platforms.
- Researchers who study self-regulation provide understandings of the motivational and emotional requirements of dedicated, intense effort, and strategies for coping with failure and disappointment, and "perceived efficacy" to maintain interest in the face of inevitable periodic setbacks.
- Researchers who have studied Mentoring or Tutoring are familiar with directed learning activities associated with implicit job "know how" and "tricks-of-the trade." Specialists in this category understand apprenticeship and other forms of one-on-one, on-the-job learning and instruction.

5.2 Measurement and Analysis Issues

5.2.1 Research Need: Rapidized Cognitive Task Analysis

For many military tasks, there is insufficient time available for training prior to deployment. For such mission-critical tasks, it will be necessary to rapidly conduct the cognitive task analysis required to inform the creation of instructional materials and methods (e.g., serious games, tough cases, etc.) that are themselves required for accelerated learning. Currently there are no baseline data on time required for deep and rich task analysis for tasks having high intrinsic cognitive load. Thus, we have no methodology and research base on the question of how cognitive task analysis itself might be accelerated (Andrews, 2009). As military missions and tasks continue to evolve and change, sometimes quickly, it is imperative that we rapidize the methodologies that are used to form training materials and methods.

5.2.2 Research Need: Proficiency Measurement and Scaling

For many military domains/jobs, including ones mentioned in the literature and discussed at the Working Meeting, continuing effort is needed to extend and refine measures of performance and achieve some level of consistency in measurement so that a potentially vast pool of empirical data becomes available. This is with respect to measuring performance beyond minimal proficiency, measurement in terms other than hours of practice, and measurement of performance at complex cognitive work. In domains where hiatus experiences are likely, performance measurement needs to be conducted just prior to the hiatus onset and just prior to re-assignment post-hiatus.

Proficiency at the highest levels ("senior expert") has been referred to as "the 5%-ers" or "super-experts" (Ziebell, 2009). Achievement at this level has to do with predisposition, personality, curiosity, drive—all the experiential and motivational factors that separate out the individuals who become experts from those who do not. While researching the notion of acceleration to highest levels is perhaps outside the scope of immediate needs and practical possibilities, measurement appropriate to this level is needed, if ideas of proficiency and expertise are to be transported into the context of selection. Across a broad spectrum of military jobs, these discriminatory aspects of proficiency might be measured in addition to the current performance measures, and individuals tracked over time. This would, ultimately, generate an empirical base and that might be of use in developing refined selection procedures.

5.2.3 Measurement for Robustness, Resilience and Adaptivity

With regard to complex cognitive work and emerging domains (e.g., cyberwork, etc.), there is an outstanding need for measures of cognitive work and "high -level" or macrocognitive skills (see Hoffman, 2009, in press; Klein, in press). There is a general concern with measuring decision making in contexts requiring adaptivity and resilience (e.g., Dodd, 2009).

Robustness is the ability to maintain effectiveness across a range of tasks, situations, and conditions. Resilience is the ability to recover from a destabilizing perturbation in the work as it attempts to reach its primary goals. Adaptivity is the ability to employ multiple ways to succeed and the capacity to move seamlessly between them. Measurement for resilience and adaptability must go well beyond traditional measures of the performance of individuals (hits, errors, rate, etc.) (Alberts & Hayes, 2003). Fundamental to the achievement of robustness, resilience and adaptivity is the opportunity to practice at problems that stretch current competency (Ericsson & Lehmann, 1996; Feltovich et al., 1997). The modern warfighter must acquire knowledge and reasoning skills that pertain to critical domain goals but which must be exercised in widely differing situations or contexts.

5.3. Factors Involved in the Choice of Domains for Possible Study

For projects to test notions of accelerated proficiency or facilitated retention, the following criteria are felt to be necessary:

1. Research should examine at least two domains, which should be substantively and interestingly different. The application of a method of acceleration to a single domain would leave open the important questions of validity and reliability, and generalizability.

2. Research should examine one or more domains that are of significance to the current and future operational needs of the military. This criterion suggests such domains as "human terrain" intelligence analysis and UAV operations.

3. Research should examine domains that are of importance across the branches of the military. This criterion suggests domains including weather forecasting. Air Force Weather and Navy Meteorology and Oceanography provide mission-critical services to Army and Joint operations. In addition, Air Force Weather already has initiatives that fit with the notions and goals of accelerated learning (McNulty, 2005). Another example domain is electrical power generation and coordination. This battalion-level mission of the Corps of Engineers provides support to

operations conducted by other branches, such as emplacement, airfield support, SASO, and others.

4. <u>Research should examine domains that have analogs in the civilian sector</u>. This criterion is important because it might engage private sector partners who, like the military, have issues of workforce, training, and knowledge management. For instance, over 60 percent of the senior engineers in the electric utilities in North America are ready for retirement, mandating intensive knowledge management programs and a need for fast-ramp training so that a next generation can quickly achieve high levels of proficiency.

5. <u>The choice of domains should give special consideration of critical competencies that ordinarily take years to develop.</u> Examples include cultural understanding, understanding and evaluation of political, cultural and economic environments of the battlespace, military implications of fused sensing and intelligence, space management for complex operations (i.e., avoiding interference), deception, influence, and information operations, and campaign replanning (Joint Chiefs of Staff, 2005).

Table 5.1. Considerations in domain choice.

DOMAIN AFFORDANCES
The domain affords study of accelerated learning in the sense of rapidized training.
Domains in which one might rapidize the transposition of lessons learned from the battlespace into the training context.
The domain affords the study of accelerating the achievement of high proficiency.
The domain affords the study of facilitated retention.
The domain transposes readily into laboratory study: Ease of study (factors including data access, availability of known and valid measures, etc.); some tasks that can be readily modeled (e.g., using simple linear models).
COMPLEX COGNITIVE WORK
The task/job work requires highly organized knowledge, reasoning skills, and motor or procedural skills as well.
The job/task work involves coping with dynamics and complexity.
Domains requiring a capacity to be adaptive and resilient.
The work involves teaming of specialists, and requires expert management of teams.
DESIRABLE PRACTITIONER CHARACTERISTICS
The work depends on skill at perceptual (re)learning, recognition-primed decision making, sensemaking, and the other primary macrocognitive functions.
Achievement of proficiency involves practice at tough cases.
Practitioner motivation and affect play a key role.
DESIRABLE ORGANIZATIONAL CHARACTERISTICS
Domains with recently transformed strategic environment, where people have more than one duty assignment.
There is organizational support for processes of achieving higher levels of proficiency.
Domains that involve work that is largely "open source."

Many candidate domains were mentioned and discussed: Accelerated Learning: Electric utilities/power generation and distribution; UAV operation; Maintenance; Emergency response; Weather forecasting; Cultural awareness and skill; UAV operations.

5.4 Knowledge Management

For present purposes, we define knowledge management as the process of capturing, preserving and sharing the knowledge and reasoning skills of experienced workers. Knowledge management combines knowledge elicitation methods with knowledge sharing and training methods.

There are a number of opportunities for new initiatives in knowledge management on the part of the Department of Defense that would contribute to accelerated proficiency. For instance, the DoD broadly does not do a systematic job of managing its expertise post retirement (SES, etc.). This is a missed opportunity and wide open for potentially valuable research.

5.4.1 Building Knowledge Models

Preservation of expert knowledge (especially for individuals about to retire) is a salient consideration in current discussions of workforce issues, technology and the world economy.

(See Section 1 of this Report.) The capture and preservation of expert knowledge is critical in many organizations and in entire sectors of the economy where there is significant risk of loss of capability.

There is no doubt that a distinguishing feature of expertise is depth and extent of knowledge. It will continue to be valuable, sometimes critical, to elicit and preserve expert knowledge. Recent IHMC experience continues to affirm the finding that senior experts possess significant knowledge for designing a process rationale, knowledge that is critical to explaining and in understanding why things are done the way they are done. Invariably in eliciting this knowledge, it is noted that someone with less experience might have made mistakes were they unaware of this knowledge, sometimes called "tacit knowledge," unaware because this knowledge is possessed by unique individuals and is undocumented.

While Concept Mapping is not the only method for knowledge capture, it is highly efficient for knowledge capture, and can be complemented by other methods. Concept Mapping can capture rationale and legacy interactions, as has already been demonstrated in some of the Concept Maps created for various specializations in the electric utilities. It is also necessary to reveal expert reasoning skills and strategies. The Cognitive Modeling Procedure (see Crandall, Klein & Hoffman, 2005; Klein & Hoffman, 2008) is a highly efficient method for generating models of practitioner reasoning and revealing differences in reasoning across levels of proficiency.

Interestingly, the process of capturing expert knowledge and skill for the purpose of preservation, feeds directly into training, and not just training in general but training with regard to acceleration. It is this convergence of applications that represents a significant leveraging opportunity for research on accelerated learning.

5.4.2 Identifying Difficult Areas

To achieve focus on high-payoff areas of study that can inform a research thrust, and to enable the research to get off to a fast start, researchers would initiate a procedure that has been used successfully in research on tough tasks, for example, in the practice of medicine (Dawson Saunders, Feltovich, Coulson, & Steward, 1990). This involves structured interviews with experts in which they are queried about concepts in that are both important and particularly difficult to learn, understand well, and apply successful in real-world applications. These are the key target concepts within the domain of practice. Experience has shown that experts can list a great many concepts and then pull out ones that are especially difficult. Agreement in responses of experts reflects various degrees of consensus and increases confidence that certain areas are fruitful ones for further study.

5.4.3 Creating Case Libraries

It is widely recognized that training must derive from cognitive task analysis and interviews with domain experts, to identify critical decision points, aspects of uncertainty and time pressure, etc. e.g., Dawson & Caird-Daley, 2009).

Arguably, any attempt at accelerating the achievement of proficiency will depend in one way or another on the creation of a case corpus. That will provide an empirical base to establish proficiency scales and will determine the "gold standards" for performance. Based on the principle that high proficiency is defined as the ability to cope with difficult cases and the empirical fact that difficult cases tend to be rare, then a corpus of cases developed for the

purposes of knowledge management would be the principal material used in scenario-based or problem-based training experiences.

The available literature shows that is it possible, and sometimes fairly easy, to build a curriculum of cases. Experts and managers, working together, are typically successful at identifying the unique and important knowledge areas in which a particular expert excels. Likewise, domain practitioners can readily identify those important concepts in a domain that seem to be especially difficult for others to fully comprehend. Any training program will have a set of concepts deemed especially important to master. There can even be some institutional surveying, investigation to attempt to establish some consensus about what these focal concepts might be (Feltovich, Spiro, & Coulson, 1993).

Methods of knowledge elicitation and cognitive task analysis would be used to generate cases. A number of well-understood methods can be used, such as the Critical Decision Method (CDM) (Hoffman, Crandall, & Shadbolt, 1998). This method requires participants to retrospectively analyze cases from their own experience that caused them great difficulty and stretched their professional capacity. The participating experts are directed to identify cases in which the targeted tough concepts played a significant role. Researchers would probe for instances of enhanced immersion, recovery from error, and adaptability/flexibility.

An important point about training complex tasks is the role of stories in the process of knowledge transfer. Orr (1996) found that "when troubleshooting complex systems, technicians tell stories because the hardest part of diagnosis is making sense out of a fundamentally ambiguous set of facts, and this is done through a narrative process to produce a coherent account" (p. 186). In relation to this, and in the context of the development of training systems, case libraries, which include expert stories, can be effective for training technical problems. Training research using such an approach demonstrates improvements in prediction and inference and in explanations (Hernandez-Serrano & Jonassen, 2003).

It will be necessary to develop a repository in which cases are scaled for difficulty relative to the different levels of proficiency. For each level we will need cases that are fairly ordinary at that proficiency levels, but also as "level stretchers"— cases that push capability beyond the current stage. The development of cases would permit the specification of the features that make a case tough (and allow investigation of how they line up with the dimensions of difficulty) (Feltovich et al., 1997). Cases would be especially evaluated in terms of "desirable difficulties," to provide insight into why concepts are difficult, which inform development and analysis for other studies.

A corpus of validated test cases can be utilized to gauge the stage of development of both trainees and practitioners. The Simplifying Conditions Method (Reigeluth, 1999) would aid in predicting difficulty and organizing the results of rating perceived difficulty. Tough cases will also be presented to apprentices, journeymen, and additional experts for them to attempt to solve, and also rate for perceived difficulty. In these tests, participants at different levels of proficiency would be guided through test cases in the same temporal sequence as the specialist who helped create the case. Information from the difficult test case can be partitioned into segments in the chronological order in which that expert originally encountered them. These segments can be presented one by one to the participant, who at each point is required to "think aloud" his or her responses and interpretations (see an application of this procedure in Feltovich, Johnson, Moller & Swanson, 1984). The responses can be compared with those of the specialist in his or her original encounter with the case.

Cases, once completed and scaled, would consist of the expert's narrative, which would weave together the hidden chain of causally related events leading to a particular problem., and associated timelines, analyses of information requirements, analyses of decision requirements, and other resources spanning the range of available media (maps, videos, etc.). Cases would be scaled for levels of proficiency, relative to individuals' levels of ability, both for routine practice and for the stretching of skill. The cases would then be used to form instructional materials that could range from paper-and-pencil study materials, to desktop exercises, to full, simulated scenario experiences.

Tough and rare cases can also be used in unlearning, to reveal knowledge shields (Feltovich, et al., 1997). Rare cases would be juxtaposed with some routine or typical cases in such a way that the learner could experience the differences that produce difficulties. Another application involves the fact that the sociotechnical workplace is constantly changing (Hoffman & Elm, 2006). New technologies, and the work methods that they shape, typically have to be integrated with legacy work methods and technologies. Conceptually, this can be viewed as a set of scenarios for practice at adaptation, not merely to handle familiar and routine cases, but to "stretch" the new technologies and work methods through application in tough cases.

Case experience is so important to the achievement of proficiency that it can be assumed that organizations would need very large case repositories for use in training (and also to preserve organizational memory). Instruction using cases is greatly enhanced when "just the right case" or set of cases can be engaged at a prime learning moment for a learner (Kolodner, 1993). This also argues for a need for large numbers of cases, to cover many contingencies. Creating and maintaining case libraries is a matter of organization among cases, good retrieval schemes, and smart indexing—all so that "lessons learned" do not become "lessons forgotten."

5.5 Training Methods and Strategies

For training across the proficiency continuum, i.e., going from Advanced Apprentice to Journeyman levels, it will be important to determine how and when to shift from (or alternate between) instruction that involves compartmentalization/routinization and instruction that focuses on interactions, complexity and tough cases. For training at Advanced Apprentice and Journeyman levels, it will be important to study issues of mentoring, such as the development of methods to identify good mentors and elicit their knowledge and strategies. In addition, it will be important to explore alternative forms of mentoring, other than the traditional form, such as the use of virtual mentors or other methods for accomplishing what mentoring accomplishes.

5.5.1 Training As A Function Of Task/Domain

The material reviewed in this Report provides some insight into how expertise can be rapidly developed. While the examples discussed in these articles are relatively applied, the theories underlying their effects are general to the science of training. One of the few viable generalizations it is that the development of expertise is contingent upon training developed for a specific context. For example, the techniques used to train skills and knowledge such as situation awareness or team coordination were developed based upon specific task contexts and constraints (e.g., Endsley & Robertson, 2000). The use of a networked simulation for military

training is especially important because it allows trainees to function in an environment that mirrors the real-world state: a group-oriented battlespace that requires coordination between physically distant teams (Fletcher, 1999; Cooke, et al., 2007). Similarly, the development of teamwork expertise in a UAV task is hastened by the introduction of waylays that would be encountered in the real world. This is effectively similar to the argument for cognitive fidelity, which suggests that training is effective when it involves the same cognitive elements as the real-world task for which the training is being conducted.

However, there is more to these studies than a simple recommendation of cognitive fidelity. The Cooke, et al. (2007) results reveal that team training for expertise is best conducted with perturbations, even when the real-world task would seldom encounter such perturbations. This allows training to target elements of a task that rarely occur, but are critical to understand and solve when they do arise. In the case of piloting, this sort of expertise can resolve situations that would otherwise result in catastrophe.

Thus, the development of expertise requires not only a training intervention that mirrors the cognitive tasks inherent to the real-world task, but also the development of skills that are rarely used but critical to success. The question that remains, then, is how to balance these two seemingly divergent needs. It is possible to envision a system that combines the various techniques described in the reviewed articles. For example, a networked team simulation that introduces perturbations (whether through alterations in team makeup or the addition of task-relevant hindrances) as part of a comprehensive training course would create a useful training tool for a group context.

Another domain factor that plays into training is feedback. Studies of diverse domains of expertise reveal a great variability between domains (and specializations within domains) in the extent to which workers receive any feedback, let alone timely, high-quality feedback (e.g., Salas, Nichols, & Driskell, 2007). In part this may explain why it can be difficult, in some domains, to identify what counts as expertise. The inherent nature of the domain can make it impossible for the practitioner to receive timely feedback (e.g., long-term weather forecasting, intelligence analysis for policy projection). This may be one reason why it can take a decade or more for an individual to achieve expertise.

For some domains of study, it may be appropriate to review debriefing methods to determine ways of shaping the debriefings so as to contribute to the acceleration of proficiency. Klein (2010) has suggested a notion of "deliberate performance" as a counterpart to the notion of deliberate practice. A Deliberate Performance method would collect and use feedback during and immediately after actual work experiences. Deliberate performance attempts to turn people into reflective practitioners. Deliberate performance analysis would have the goal of encouraging the learner to become a reflective practitioner through activities including explanation and extrapolation.

5.5.2 Training as a Function of Proficiency Level

We have a strong foundation of knowledge and theory on expertise. For example, in the context of improving learning in classroom settings, Lajoie (2003) suggested that "identifying what experts know can help determine the trajectory towards competence for that task" (p. 21) and guide the development of content appropriate for differing stages of learning. However, there is a considerable qualitative and quantitative gap in between the knowledge and skills of the expert and those of the novice. For accelerated learning what is critical are:

1. The gap from initiate (individual receiving introductory training) to senior apprentice,

2. The gap from apprentice to journeyman, and

3. The gap from journeyman to expert.

Fiore, Hoffman and Salas (2008) presented the following set of testable hypotheses concerning training as suited to novices, initiates, apprentices and journeyman. For the focus of the present Report, we note their claim that at the apprentice level mentoring is especially important, where appropriate actions and decisions are illustrated in the context of the actual operational environment and, when warranted, the learner is guided in his own performance (Collins, Brown, & Newman, 1989). Training needs to reveal and resolve the "knowledge shields," which are strategies or rationalizations for sticking with simplified understandings even when evidence suggests that concepts are wrongly understood (Feltovich, et al., 1997). Here the learner must recognize incorrect understanding or assumptions and resolve any misconceptions he may hold. As such, corrective feedback via expert mentoring or within a simulation-based learning environment is critical.

At the Advanced Apprentice and Journeyman levels, notions of CFT and CTT come into play, related to their emphasis on learning at advanced levels. The learner needs to be presented with environments presenting highly variable sample tasks and rare, difficult examples that challenge the learner's concepts and categories. Adapting to such challenges leads to a richer representation of a domain and supports flexibility in later problem-solving situations. Given their developing autonomy, those at the Advanced Apprentice and Journeymen levels might independently use simulation-based environments to train on these types of learning situations.

It has been said that apprentices make the same mistake twice, journeyman make the same mistake once and experts work until they never make mistakes. But domain specialists of high proficiency are intrinsically motivated so seek out corrective feedback that allows them to perceive their errors (Sonnentag, 2000). The more highly experienced and motivated domain practitioners seek corrective feedback from coworkers. When everything works the way it is supposed to, one is less likely to receive feedback about what did not work or what might have been done better. As such, experts seek out feedback pointing out targets for improvement.

What counts as useful feedback depends on the proficiency level of the individual whose performance is being evaluated or who is in training. It has been speculated that novices learn more from successes because they need help figuring out what to do, whereas experienced people learn more from failures because they have already mastered the routines and are in a position to make use of the information found in errors. In fact, would-be experts, when they practice, will inevitably encounter more failures than lesser learners because they focus on developing skills beyond those with which they are already comfortable.

CFT and CTT suggest feedback should help the learner transcend the inclination to invoke a knowledge shield (i.e., rationalize away a misunderstanding), and un-learn concepts or notions that incorrectly simplify their understanding of the domain.

Research shows that for promoting the achievement of proficiency, feedback needs to be:

- *Timely*, that is, close enough in time to the point of decision or action to be informative but not so close as to prevent the decision maker from thinking through what had just happened,

- *Satisfying to Sensemaking and Plausibility Judgment*, in terms of causal explanation,
- *Informative of Outcome and Process*, explaining what happened and analyzing the decision maker's reasoning.

5.5.3 Scenario-Based Training

In section 5.4 above about Knowledge Management, we discussed the need to develop libraries of cases, scaled for difficulty, and that such a corpus could be used as training material. People learn what they practice; hence, to achieve adaptive expertise, they should practice in many ways, across many kinds of cases (including ones that involve the same basic principles, but in different kinds of contexts), using many kinds of conceptual tools, points of view, mental organizational structures, investigation and practice strategies, and the like (e.g., Feltovich, et al., 1997). The modes and means of training should engage real work practice, the challenges, contexts, and duties of the job, to the greatest extent possible.

Training for the acceleration of proficiency in domains of complex cognitive work will have to include an appreciation of the importance of causal reasoning, anticipatory thinking, and problem detection. In order for the practitioner to be better able to handle complexity, especially unexpected complexity, training must involve helping people acquire a more powerful toolbox, and acquire skill at knowing how to build entirely new tools when tough cases arise.

Given that experts often extrapolate from patterns of cues and think in terms of rich causal models, the simulation scenarios would be set up such that the learner is sometimes led and sometimes misled in seeking solutions (of course, while not deviating from authenticity). In the case of being misled, the idea is that the simulation purposely misguides a learner into a common solution, but the reality is that the error is due to a little known or subtle issue. For example, with regard to ordering, an appropriately crafted scenario can manage temporal sequencing to support problem solving. This could juxtapose real-world time with narrative time, so that the learner can experience the event through the perspective of the expert (real-world time), and through the more omniscient, third person perspective of narrative time, that is, presenting events in alternate directions so as to highlight or prominently position certain occurrences for interpretation by the learner. Simulations allow for tremendous flexibility in manipulations of fidelity—differing kinds and amounts of contextual richness. These variations are important because they can emphasize particular elements of the scenario to the learner.

5.5.4 Simulation-Based Training

Throughout this Report we have referred to training using technology spanning games, to computer simulations, to virtual reality. Characteristics of effective scenario-based training are listed in Table 4.8, above, and include realistic environments, mentoring, and focused feedback. A clear consensus is that simulation-based training is critical, necessary, and has at yet untapped potential (Fletcher, 2009).

Simulation-based training is an instance of minimizing the transfer distance.

> The expert knows there is no substitute for going out to look at the problem yourself… out there smelling the ashes. [We need to] bottle these experiences to simulate them… [the] look and feel and smell of critical events is what defines the problem (Ziebell, 2010).

The modes and means of training should engage realistic work practice, including the challenges,

contexts, and duties of the job. Sometimes less realistic practice is effective, as well as more cost-effective, especially for earlier stages of training. This might also be true for advanced learning, in certain circumstances. But to generalize, training at advanced levels should be a short "transfer distance" from the work context. This encompasses everything from instructional settings, tools, workshop exercises, problem-based learning, and real-time mentor guidance, as in apprenticeship on the job (Collins, Brown, & Newman, 1989; Brown, Collins, & Duguid, 1991). Learners can see the value of what they are trying to learn because that value is apparent in the work they are actually doing, and the transfer (of knowledge) conditions and application criteria are likewise relatively salient (e.g., Bransford, et al., 1990; Coulson & Feltovich, 1993; Lesgold & Nahemow, 2005).

Scenario Content – What is the problem being represented? First, with regard to scenario content, the scenarios would need to address integrative complexity arising from the interaction of legacy and modern systems. Conceptually, this can be viewed as a set of scenarios where the troubleshooting and diagnosis sensemaking systems with new systems, or, more likely, new with old systems. Further, these rare cases would be juxtaposed with typical cases in such a way that the learner can experience the differences that produced the problem and recognize the differences of the diagnostic cues in each.

The simulation scenarios would be set up such that the learner is sometimes lead and sometimes misled in their solution seeking. In the case of being misled, the idea is that the simulation purposely misguides them into a common solution but the reality is that the error is due to a little known issue associated with an interaction between a legacy system and modern devices. This will address the problem demonstrated by Besnard and Bastien-Toniazzo (1999) who showed that experts sometimes made errors in electronics troubleshooting by developing a fixation on a particular component that suggested it was at fault. Training needs to encourage "systems thinking" (Linou & Kontogiannis, 2004) that trains about functional, temporal, and causal-link information. Patrick (1993) found that systemic information supported both retention and the ability to reconstruct the task cues.

Narrative Structure – How does the story get told? Given the multi-faceted nature of telling stories and the complexity of the operations and maintenance tasks, research needs to attend to the manner in which events and episodes are woven together within the simulation. Narrative, as the formal apparatus of storytelling, should be used to weave together the sometimes hidden complexities of causally inter-related events leading to a particular problem. More formally, narrative determines how the story gets told, that is, who tells the story, the degree of omniscience held, the ordering of the events, and descriptiveness of the setting. For example, with regard to the ordering, an appropriately crafted scenario can manage temporal sequencing to support problem solving. This could juxtapose real-world time with narrative time so that the learner can experience the event through the perspective of the expert (real-world time), and through the more omniscient, 3rd person perspective of narrative time, that is, presenting events in alternate directions so as to highlight or prominently position certain occurrences for interpretation by the learner.

Story Representation – How is the story represented? Simulations allow for tremendous flexibility in manipulations of fidelity, which can provide differing amounts of contextual richness. These variations are important because they can differentially emphasize particular elements of the scenario to the learner.

5.5.5 Training for Problem Recognition

Much expert problem solving is done by recognition of problem types and difficulty (e.g. Feltovich et al., 1997; Hatano et al., 2003; Klein & Baxter, 1998). Experts' categories for fall also at a functional rather than literal surface feature level (Glaser, 1987). Thus, experts can rapidly evaluate a situation and determine an appropriate plan of action, a phenomenon called "recognition-primed decision making" (Klein, 1993, 1998). Within the first second of exposure to a novel chess position, chess experts can extract important information about the relations of the chess pieces' positions, and begin identifying promising moves (Charness, et al., 2001).

Yet experts also realize when their routine ways are inadequate to the task. Typically this switch requires notice that something is unusual about the problem. By using cases that represent the typical, along with tough cases, training can be in the detection of unusualness (e.g., switching from mainly recognition-primed decision making to some more deliberative form of reasoning), since, almost by definition, tough cases will contain tricky or unusual aspects. Training can manipulate the operative cues within the cases that indicate the cases are unusual—from low level cues that are consistent with simple interpretations (the "easy" side of the dimensions of difficulty, static compartmentalized, etc.) to ones in which the operative cues are complex (e.g., relational, dynamic, interdependency-based).

It is also clear that these cognitive-perceptual abilities take time to develop and result in new (and effective) ways in which experts view and interpret the world (Chi, Feltovich, & Glaser, 1981; Klein & Hoffman (1993). Since this area of development is so crucial to the development of expert performance, it must also be a focus of training for skill improvement (e.g., Fadde, 2007), and it, like other skills discussed, is probably most amenable to case-based kinds of learning/practice.

5.5.6 Training for Perceptual Learning

Skill at the perception and integration of data is critical for many, if not most domains of complex cognitive work. Experts can perceive things that are invisible to novices (Klein & Hoffman, 1992). While it has proven difficult to capture "perceptual learning" in the lab is a challenge, the results of perceptual learning have been shown in studies of expertise in a variety of domains ranging from neonatal critical care nursing to commercial fishing. Studies have looked at domains where perceptual skill is paramount, such as radiology (see Goldstone, 1998; Lesgold, et al., 1988) and baggage screening (Fiore, et al., 2000). We know that experts' knowledge organization involves finer gradations of functional categories, that is, "basic object-level" categories fall at a finer level than for non-experts. For example, limestone is simply a kind of rock to most people, but to the expert, there are many variants that inform of geological dynamics (e.g., tilted thinly interbedded limestone-shale with limestone predominating).

Perceptual learning is not just about the perception of cues or the reckoning of variables, it is about their meaningful integration. A case study from the U.S. Army Corps of Engineers is presented in Textbox 5.1.

Textbox 5.1 A case study in perceptual learning.

Terrain analysis is a process in which aerial photographs are interpreted to assess soils, bedrock, vegetation patterns, drainage patterns, and the like. In one experiment (Hoffman, 1987), an expert was presented a photograph for inspection, but was only allowed two minutes of viewing time. Ordinarily, the full systematic terrain analysis process can take hours. After the viewing period, the expert was allowed two minutes in which to report everything that could be remembered about the photo. In one particular trial, the expert began his retrospection by asserting that any personnel sent to the depicted area would need to be prepared for certain types of bacterial infection. The experimenter's response was, "You can see bacteria in a pond taken from 40,000 feet?" Here was the reasoning sequence that the expert recounted: The photo covered an area of tropical climate. The vegetation was mature and uniform, so the contours to the top of the underlying soil, and since the soil layer would be relatively thin, the contour to the tree canopy reflected the underlying bedrock, which appeared to be tilted interbedded limestone. The bedrock also determined the pattern to the streams and ponds, and there appeared one pond that did not have a tributary running away from it. Given the climate, the vegetation (tropical legumes) and the stagnant water, the presence of bacteria was a virtual certainty. This appears to be a long chain of inferences, dependent on a great deal of declarative knowledge. Yet, in the actual experimental trial, the expert's judgment was the sort that one might be inclined to call "direct" or "immediate," a perceptual phenomena rather than a linear, deliberative process.

The informative cues might be separable in the sense that they can be operationally defined and measured independently of one another, but they link together for principled reasons and relate to one another in meaningful ways. In functional terms, they are *integral* (Phelps & Shanteau, 1978). Goldstone (1998) has referred to this as a process of "unitization," in which a "single constructed unit represents a complex configuration" (p. 585).

Often, the patterns that bear meaning cannot be defined in terms of the simple presence or absence (or the values) of each of a set of separable cues (which is how "pattern recognition was traditionally defined). Meaningful patterns are sometimes defined by the relations among functionally integral cues. Ludwig Wittgenstein was getting at this with his notion of "featureless family resemblances." For instance, the expert weather forecaster can see a "gate-to-gate signature" in radar that is a clue to tornado formation. This signature is a function of a *difference* (is a relation) in relative velocity (is a relation) of proximal (is a relation) winds, with strong (is a relation) winds moving toward the radar (is another relation) in very close proximity (is yet another relation) to strong (is a relation) winds that are moving away from (and, again, another relation) the radar. Clearly, a considerable nexus of relations. The patterns that are meaningful to experts:

- Sometimes involve individual cues,
- Sometimes involve sets of separable cues with some cues being necessary and some being sufficient,
- Sometimes involve patterns that can be defined in terms of combinations of cues,
- Sometimes involve patterns defined in terms of relations among cues,
- Sometimes are featureless family resemblances where cues are neither necessary or sufficient when considered individually, and

- Sometimes involve meaning that resides in the relations among cues that are integral, or cue configurations.

In complex sociotechnical work systems, decision makers rely on multiple data types, and data that are also in continuous flux. This takes the traditional notion of "pattern recognition" to entirely new levels, because the meaningful patterns are typically dynamic, that is the important meaning and relational information exists only over time.

In aerial photo interpretation, the patterns that experts perceive, even in static images, are dynamic (Hoffman & Pike, 1995). Experts perceive processes. Furthermore, the dynamic cue configurations sometimes exist only across multiple data types. The patterns experts perceive sometimes do not exist in individual data types. Indeed, the really critical information often is "trans-modal"—exists *only* across data types. For instance, in weather forecasting the radar images are not the only thing that is guiding sensemaking activity and shaping the forecaster's formation of a mental model. A great many other data types are involved, such as satellite images, computer model outputs, wind fields, pressure data, and so on. The "Aha!" moment might come when viewing radar, but the mind had been prepared in the sense that a mental model was based on an integration of meaningful patterns that only exist across data types. Likewise, the expert terrain analyst makes determinations when viewing aerial photos, but has engaged in systematic analysis of other data, such as maps.

To raise the benchmark for proficiency even higher, one must take into account the "Moving Target Rule" (Ballas, 2007; Hoffman & Woods, 2005): The sociotechnical workplace is constantly changing, and change the technologies in the workplace will entail change in the work to be accomplished, even if the domain constraints remain constant. Change in cognitive work comes because of changes in goals (i.e., new tasks, new challenges) but especially because of changes in technology, including changes in data types and display types. For instance, the NEXRAD radar has revolutionized radar meteorology and forecasting, and new radar algorithms are being introduced all the time, resulting in new data products (hence, new displays), and new combinations of data types (e.g., "Sat-Rad" displays that combine satellite imagery with radar data).

In the modern sociotechnical work context, the expert must engage in frequent, if not nearly continuous *perceptual re-learning*. Patterns previously learned and perceived in one way come to be perceived in a new way. Experts engage in perceptual re-learning of dynamic information defined over sets of integral cues that are trans-modal (they exist over different data types).

A critical scientific gap is the paucity of research attempting to capture the perceptual re-learning of dynamic cue configurations that exist across multiple data types. We need to know more about how it happens in domains of expertise. Available research gives only the barest of clues.

Any method for accelerating the achievement of proficiency could consider supporting the processes of perceptual re-learning. In domains of expertise where perceptual skill is paramount, such as baggage screening or weather forecasting (Fiore, et al., 2004), it seems reasonable to speculate that providing critical exemplars of targets makes the perceptual learning process possible, but it may not accelerate it. One might expect that a requirement to engage in perceptual re-learning will be effortful and disruptive even for experienced domain practitioners. But experienced practitioners should be able to re-acquire expertise in less time than less-experienced practitioners (students, journeymen) acquire it.

5.5.7 Training for Robustness, Resilience and Adaptivity

In domains of dynamics and complexity, the work (including the technologies) is continually changing and thus mental models have to change (Mumaw, et al., 2000). Robustness is the ability to maintain effectiveness across a range of tasks, situations, and conditions. Resilience is the ability to recover from a destabilizing perturbation in the work as it attempts to reach its primary goals. Adaptivity is the ability to employ multiple ways to succeed and the capacity to move seamlessly among them. Fundamental to the achievement of robustness, resilience and adaptivity is the opportunity to practice at problems that stretch current competency (Ericsson & Lehmann, 1996; Feltovich, et al., 1997). Training cannot oversimplify. In trying to train for the ability to handle complexity, there have traditionally been two general approaches. The first is to simplify and gradually add in complex elements. While this seems highly intuitive, and may be the most common mode in education and training, for highly complex material it can backfire. Learners can get stuck in the simplifications and petrify there (e.g., Feltovich et al., 1989; 2001, Spiro, et al., 1989). Another is to address the real complexity, but at the same time make available ample expert and mentoring help. Some of the most outstanding real examples of experience and learning acceleration for highly complex material and tasks have used this latter approach (Bonsangue, 1993; Lesgold, Lajoie, Buzno, & Eggan, 1992; Palincsar, Spiro et al., in press). These programs have used practice problems and materials that were at least as hard as or harder than what the learners were prepared for.

Too achieve adaptability, training needs to utilize "concept-case coupling." Training must involve the learning of conceptual knowledge, i.e., regularities, general principles, laws, and so forth. These are the abstractions that apply across cases of application of these principles and, thus, are a vehicle for transfer. But because these are abstractions, such conceptual knowledge must be applied to the details of a case of application, details that require the contextual tailoring of the principle for application in some cases or can even render a concept not applicable at all. Training must include considerable opportunity for practicing the application of conceptual knowledge across ranges of cases, for example, through guided apprenticeships or the use of case-based practice technologies (e.g., Collins, Brown, & Newman, 1992; Lesgold & Nahemow, 2005; Spiro, Collins, Thota, & Feltovich, 2003).

People learn pretty much what they practice. Hence, to achieve proficiency and high proficiency within a domain, people should practice in many ways, across many kinds of cases (including ones that involve the same basic principles, but in different kinds of contexts), using many kinds of conceptual tools, points of view, mental organizational structures, investigation and practice strategies, and the like (e.g., Bransford, et al., 1979 Spiro et al., 1989, 1992). For example, individuals should cross-train with others in the organization, those in different work positions, so one can see how the world looks from that vantage point.

All these considerations lead to a particular simulation-based training method.

The Operational Simulation Method

The OPSIM method developed by WRTI, Inc. (DiBello & Missildine, 2008; DiBello, Missildine, & Struttman, 2008) was discussed above in Section 2.7.a as an example of a successful demonstration of acceleration, successful in a number of different business domains. It would be prudent to attempt to adapt this method to other domains and training contexts. The method is a simulation exercise in which participants engage with a "reality analogous" version of their organizational environment in a compressed time period. In doing so, participants confront

organizational failures and rehearse strategic solutions while being held accountable to outcomes. Participants work as a team to solve difficult problems, and in so doing leverage and share their individual expertise. This leads to novel solutions, such as new ways of coordinating decision making among multiple organizational entities, and implementing a new information technology or resource planning system.

Essential to the success of method is reorganizing participants' "default mental models" (or "business as usual" approaches to solving a problem) in order to meet the novel demands of the goals that have been designed into the environment. To achieve this, however, the default mental model must first be expressed and analyzed. Because cognition and activity are inextricably linked, a workplace cannot simply add new mental models on top the old. Just as architects must often tear down old structures before they can rebuild, so the individual mind and the organizational brain must clear away the default mental model, before novel ways of working can emerge. This certainly fits with the ideas of the CFT/CTT merger.

In the training, the participants must actually run an emulated version of their organization with several interacting functions, attempting to meet or exceed their goals under a time pressure (e.g., often a "month" is 20 min in a manufacturing exercise). The immersive simulation aspect of the exercise is what activates the default mental model. Participants engage "as though" they are at work. Adding to stress, participants "play" for 8 hours or more at a stretch while getting dynamic, real time, granular feedback about their performance in a compressed time period, within the micro environment. At any moment, participants can measure their performance against a hypothetical ideal in order to tell how far they are from the ideal on any of the parameters being measured during the exercise. Invariably, any major organizational breakdown that is present in the real life work environment is replicated by the participants during the exercise; i.e., the group invariably "fails" in a way that mirrors their current problems in the real workplace.

Of course, this sounds remarkably similar in overall structure to the way exercises are conducted at the National Training Center.

In the Day 2 of the exercise, participants are given feedback based on various performance measures from the activities of the previous day. The participants discuss: 1) what went wrong, 2) what we will do differently this time, and 3) how will we know it is working. They then run through the exercise a second time. They must make their "new" plan work under the same time pressure as before. Invariably, participants doing the exercise a second time after failing once manage to meet or exceed the goals and develop innovative and detailed solutions that prevent the problems encountered before.

WRTI has found that the gains are transferred back to real work as fully rehearsed tactical plans and results are normally seen in the real work places within weeks or months.

Scenarios such as war games and flight simulators often do an amazing job at replicating real-world environments. However, these kinds of simulations are primarily useful for learning a specific, standardized set of procedures, plans, or certain emerging strategies. These kinds of simulations often pre-designed a particular method to which the participants must adapt. The purpose of these simulations is not to allow new design solutions to emerge. The OpSim™ method has several features that set it apart from other simulation exercises.

- It is suited to training for work in complex sociotechnical systems where adaptivity and resilience are critical.

- It is suited for complex coordination and implementation scenarios in which people have to solve multiple problems at once.

- It is dynamic enough to synthesize solutions for both high level, strategic problems and front-line, operational issues rooted in entrenched, default mental models.

These ideas and findings hearken to those of Schmidt and Bjork (1992; see also Valkeavaara, 1999), that schemes of learning which are in the short run harder, and often even less effective in the short run, can yield long term advantages in both retention and transfer 'punch.'

Decision Making Exercise

The Decision Making Exercise (DMX) method was developed initially to train high-level decision making skills for military commanders (Klein, 2003). A similar method was created by Lia DiBello (2006). The trainer provides information about a critical event, asks the candidate to make a prediction about some unifying variable, shows the actual data, and then continues requesting predictions and providing feedback as the scenario unfolds. The issue is not whether the person can generate an accurate prediction from the start. Rather, the issue is how quickly the person improves. The best people will revise their mental models to improve their predictive accuracy based on what they can learn. In the versions of the method conducted by Klein Associates, trainees in military command were presented scenarios that consisted of a map or diagram plus a one-page description of events thus far, unexpected continuations, and the challenge to forge a decision on the spot. These exercises are intended to be played in groups, with a facilitator, but they can also be played on an individual basis. As the participants walk through the re-creation of a tough-case decision situation, they can be fed information as needed, or as it would unfold in actual situations (but time compressed). Note that these exercises differ from decision making games in that there is no one single best or good solution. Rather, the participants must navigate through trade-offs.

While not having single "best" answers, exercises can be formed on the model of the simple game. In this form the decision exercises are easy to play, can be played fairly quickly, are technologically simple, have simple rules, are flexible and adaptable, and are very transportable —they should be capable of being played in a lunchroom or during travel layovers. Each exercise is simple because it focuses on only one or a few particular key concepts, principles, or lessons learned.

If a decision exercise were to be made higher fidelity, it could be thought of as a form of simulation. Simulations at some level of fidelity may be useful in utilities training. Computer-based simulations are increasingly being used to teach abstract or conceptual information (Miller, Lehman & Koedinger, 1999; Resnick, 1994; Schank & Farrel, 1988). By providing perceptual grounding of abstract concepts, they aid comprehension, and the interactivity can support a deeper understanding of the material (Goldstone & Sakamoto, 2003).

Decision Making Exercises, whether the brief form or the simulation, have some general features:

- A meaningful title,

- Background information describing and perhaps explaining the current situation and its origins,
- A narrative description of the scenario itself, taking the form of a compelling story that builds to a climax—a dilemma—putting the participants on the hot seat, forcing them to make a decision to resolve the situation.
- Some sort of visual representation that accompanies the narrative (diagram, map, etc.).
- If meant for team decision making, some sort of role assignments.

Team exercises often involve an energetic exchange of opinions. The actual decision is less important that the thinking that goes into it. The decision exercise is a vehicle for triggering the decision-making process and then allowing individuals to reflect on it or discuss it with others. Exercises can be used to build a familiarity and mutual understanding within a team, so team members know more about how others are likely to react to certain types of situations.

Exercises come from personal experiences, which are described as narratives. Exercises are formed around specific experiences and their context. Exercises are not based on general or typical situations. "We need context in order to exercise our intuition." (Klein, 2003, p. 41) For developing instructional cases, domain practitioners are generally able to identify, and recall, previously encountered tough cases. In addition, managers can often see where staff members repeatedly struggle with some type of judgment or decision. Both the practitioner and the manager can recount personal experiences. From these one can create a timeline for the described event, and for each key decision in the event, a list of the information requirements of the decision maker. Decision Requirements Tables serve the dual purpose of formulating a description of the type of dilemma that needs to be practiced, and they can help form the tough cases to be use in decision exercises.

Another benefit of construing a decision exercise as a game is that one can hold Tournaments. In a DMX Tournament, multiple teams (each composed of a few to a handful of people, all having different specializations) each craft their own decision exercise and then all the teams work on the exercises of the others. Then, in a final whole group discussion, people can compare notes on what was frustrating them, and what made exercises challenging for others.

> Several of the participants planned to set up periodic "field days" during long lunch breaks. They thought that routinely having their colleagues make up and play decision games would be a good chance for cross-functional learning, for making connections, and for building intuitive decision-making skills. Having the decision games center around real issues meant that the decision games were directly relevant to their work and provided a way to make sense of problems that were troubling them. They even decided they could bring the games to upper management to help them articulate their frustrations (Klein, 2003, p. 42).

Klein (2004) argues that Decision Making Exercises can help individuals:

- Broaden and enrich their mental models
- Establish relationships among concepts and cases
- Appreciate the importance of critical cues and patterns
- Fill in the gaps in their experience base
- Learn ways to better handle uncertainty

- Practice at resolving conflicting goals
- Learn to perceive how to spot leverage points - the starting points for constructing new option
- Learn how to detect and anticipate problems
- Understand situations from alternative perspectives
- Practice at allocating limited resources
- Acquire technical knowledge more quickly, by putting it in a practical context
- Practice at giving directions or presenting clear statements of assessments or intentions.

The Tournament may be useful for individual utilities companies but may also be run at the corporate level, if one were to, for example, hold decision exercises for Bulk Power Operations personnel from a number of subsidiary companies. In this case one thinks of expertise acceleration not in terms of being faster at getting an individual up to expert levels but better at spreading the corporate expertise around—getting the organization as a whole to increase the rate at which it shares its expert knowledge and skill. This Tournament notion may be of value to utilities that seek to share, as well as accelerate, their expertise, for the sake of promoting the industry. In particular, tournaments may be of value in generating a new national-level cohort prepared to launch the next generation of nuclear capabilities.

5.5.8 Training for Teamwork

The study of team cognition and coordination is relatively new (see section 2.6, above) but the research has made clear that team process can be studied, team performance can be measured, and the quality of teamwork evaluated. We have a rich corpus of concepts with which to make useful distinctions: task work vs. team tasks vs. teamwork; team vs. individual mental models.

Many of the above findings and ideas about acceleration that have been discussed in this Report have implications for training for teamwork and team skills. For example, much of the training for resilience and adaptivity is training of teams. All of the domains that have been discussed in this Report involve teaming and therefore a need for team training (see Table 4.1, above). All of the larger-scale exercises we have discussed (the NTC, Operational Simulation, etc.) are methods that train teams at the same time they are training individuals Time compression can apply to simulated cases involving problem solving by teams, and not just individuals. Decision Making Exercises and Anticipatory Training exercises involve problem solving and discussion by teams, and not just individuals.

In many military jobs and missions, military people do not stay together in teams. It is hard to keep people in the military together as people get transferred. War has its own effects that work against the notion of building expert teams. Training for high levels of team proficiency must involve training in team tasks in addition to training in the teamwork.

- An outstanding challenge is "how to turn a team of experts into an expert team," how to turn a new team into a high-functioning team.
- An outstanding challenge is how to train for team skills such that a set of proficient individuals can rapidly compose itself ad hoc to form a high proficiency team.
- An outstanding challenge is to ask "the hiatus" question concerning teams. In what ways might team skills decay due to hiatus experiences.

- An outstanding challenge is how to conduct knowledge management for team skills, that is, the capture, preservation and reuse of knowledge and skills specifically with regard to team tasks and teamwork.

Attempts at acceleration—in any of its four senses—could contribute to our ability to promote teamwork and team training by advancing theory and method in the study of team cognition and collaboration.

5.6 Facilitated Retention of Skill

5.6.1 Opportunity: Reserves Training

It might be possible to establish a research project in collaboration with Reserve Units, representing an opportunity to study retention and retraining.

5.6.2 Targeted Research Need: Measuring Retention/Decay and Hiatus Effects

There is a consensus on two outstanding needs. One need is for better measures of over-learning. Proficiency can and does continue to increase even after performance achieves some metric for competence (minimal or otherwise) on any given measure of performance. For example, air traffic controllers continue improving their skills long after they achieve a criterion of "no errors" in the simulation-based training. We know that practice trials or time in practice only partially correlates to increasing proficiency. This is as likely as true for performance after achieving some criterion as it is for performance before achieving some criterion. On the other hand, with more time in performance there is an increasing chance of encountering tough cases, which also contribute to increases in proficiency.

> In some domains, experts make very few, if any errors. Examples are air traffic controllers, short-term weather forecasters, insurance actuaries, photo interpreters Experts keep improving and thus "percent correct" is insensitive. How can we assess performance that keeps improving? We need to compare various measures for evaluating behavior that is "better than perfect" (Shanteau, et al., 2002).

One method that is suggestive of new possibilities is the Cochran-Weiss-Shanteau Index (CWS). This index is reminiscent of the notions of signal detection theory in that it is formed as a ratio of discrimination to inconsistency. Finer discrimination and less inconsistency entail better performance. It is a relative index (therefore not bounded as are singular measures of positive performance (percent correct) or errors. It is nevertheless sensitive to errors, more so than peer judgments of performance (Thomas, et al., 2001). Also, values can only be compared within domains. This and other measures might be brought to bear in studies of high proficiency in military domains, as Friel, et al. (2002) and Thomas, et al. (2001) have shown for the case of air traffic control.

5.6.3 Targeted Research Need: Hiatus Training to Prevent Decay

With regard to issues of decay/retention, especially following hiatus, loss of skill on the part of pilots has been the prototype for discussion. Many considerations enter in. Loss of skill due to hiatus will likely continue to be a problem as the Air Force makes trade-offs between capabilities of warfighting and capabilities of administration. Some performance data show only modest loss of skill and reasonably rapid reacquisition of skill following hiatus. Piloting and training have been studied extensively, but for acceleration research there would be a need for new measures of performance, over-learning, and proficiency level. On the other hand, semi-standardized programs for refresher training represent tradition, are entrenched in both the Air Force and the Navy, and are ipso facto adequate. Another paradox at play is the fact that duty assignments during hiatus generally leave little time for practice or refresher training.

Social Networking might play a role, permitting pilots to keep current on checklists, procedures, and simulations of various kinds and contacts with active flyers (e.g., through blogs) for keeping up with tactics and equipment advances.

Psychological research has shown that "mental practice," which is practice within the medium of thought, imagery and the kinesthetic sense, can lead to performance improvement. If viable, mental practice might play a role in hiatus training for skill retention. Since in the hiatus situation it might be inconvenient or impossible to practice a skill, especially if the skill requires special equipment not readily available. The question arises as to whether mental practice can provide a reasonable substitute for actual practice in those circumstances. In one study using a data entry task, participants practiced typing four-digit numbers by actually typing or by just imagining the typing movements. Mental practice participants showed improvements in typing skill equal to that for the typists. When practice involved a key configuration different from that used at testing, participants who used physical practice, but not those who used mental practice, suffered from interference (Healy, 2007).

5.6.4 Targeted Research Needs: Rapidized Updating

"Rapidized Updating" would leverage an institutionalized knowledge management process to rapidly transition workplace changes into a mockup (of suitable fidelity) and thereby enable pilots to practice at what has changed in their work context. This new concept might be investigated in collaboration with DoD Programs that are currently focusing on the notion of accelerating the transition of lessons learned from the battlespace into the training space.

5.7 Accelerated Achievement of Proficiency

We begin this final section of this Report by presenting vignettes based on the responses of Working Meeting participants to the core questions of the meeting.

5.7.1 Four Vignettes

Vignette #1: Task Analytic/Factorial Experiment Approach

> I would take an analytical experimental approach to the issue of accelerating the achievement of proficiency in some selected domain. In particular, I would start by breaking down the required

tasks in the selected domain into component subtasks. I would then conduct experiments that isolate the various subtasks to test specific hypotheses about how to optimize not just the efficiency of learning (speed) but also its durability (retention across delays) and generalizability (transfer from one set of circumstances to another). In particular, I would conduct experiments to test whether training principles developed in my previous research apply to these component subtasks. For example, I would test whether the procedural reinstatement principle applies to the subtasks in this domain. By this principle, for procedural information (skill learning), retention is strong but transfer is limited, whereas for declarative information (fact learning), retention is poor but transfer is robust. For another example, we have been able to improve fact learning to a huge extent by using the strategic-use-of-knowledge principle, by which learning and memory are facilitated whenever pre-existing knowledge can be employed as a mediator in the process of acquisition. I would test whether that principle might also be used to accelerate the learning of subtasks in the selected domain. I would further hope to conduct experiments aimed to develop new training principles for accelerating the learning of subtasks in the selected domain as well as for enhancing the retention and transfer of the learned subtasks.

Minority Report: While task analysis of a number of forms will certainly be a component of research on acceleration, an assumption of this vignette is that the analysis will be of fixed tasks. A second assumption is that the demonstration of acceleration is identical to controlled laboratory experimentation on familiar effects and principles. While both assumptions define a valid research space, they are bounded when seen in the context of complex cognitive work systems, which have changing and emergent goals typifying the evolving work of the military.

Vignette #2: Train Maintenance Tasks Using Augmented Reality

If I had an opportunity to accelerate the achievement of proficiency in a selected domain, I'd first select a domain that would be relevant to military requirements and that would afford a cost-effective opportunity for experimental work. For these reasons, I'd probably pick maintenance as the domain since it is common across many fields and civilian/military environments, it's subject to technological advancement and knowledge/skill loss, something that could be studied in an academic lab, is suitable for performance measurement with little additional instrumentation, and also suitable to experimental manipulation (e.g., number of programmed faults or their probability). The potential subject populations of novices and experts could be large if say auto maintenance was chosen as the operational context, another advantage. I'd then choose independent variables that might yield the most bang for the buck, and consider not only variables that might promote learning but also ones that seem to be holding it back, such as sleep loss and

interrupted learning or practice (due to multitasking within the military). As a favorite, I'd consider how new technology, such as augmented reality, could be used in both a schoolhouse and a deployed setting (i.e., as part of an embedded training system in operational equipment). I'd choose this technology for study because many nations are moving to embedded training, but little is known about its efficacy. Augmented (mixed, fused, VR etc.) are potential enablers of embedded training. It makes sense to me to investigate potential technologies or interventions that could apply in an operational military setting where the benefits could be large (e.g., mechanics having to learn quickly how to diagnose and repair a new piece of kit introduced directly to the field). I'd want to compare learning rate, transfer effectiveness, and retention (different intervals) associated with this approach to conventional training methods.

Minority Report: The selection of a domain having military and civilian instantiations is a key aspect of this vignette. If a domain such as this were chosen, a concerted effort would be required to avoid any focus on fixed tasks. The main idea for acceleration is virtual reality and embedded or on-the-job training. A current analog would be the EPRI use of VR to train for maintenance in a nuclear power plant's "hot room."

Vignette #3: How Trainers Do It Now

I'll argue that in our projects we already accelerate the achievement of proficiency, in our simulation training systems. Which is not to say we cannot improve the process. The process is not probably conceptually different from many others. It requires: subject-matter experts; critical tasks; critical skills (note, we focus on skills, not knowledge) that underlie critical tasks; performance measures for critical skills; and specific actions (sequenced, when necessary) that define proficient performance. We model the student's current skills proficiency and to devise the most-appropriate next lesson in crawl-walk-run fashion to address something like the student's zone of proximal development. So what is it that is in any way special? I'll put forth six possibilities, with one-sentence descriptions doing no justice to the lengths of papers to which each refers.

1. Scenario-based training. The student acquires and practices skills to the extent reasonable (not "the extent possible," since it depends on cost-effectiveness) in a realistic setting.
2. Scenario-based assessment. The student demonstrates skills in a situation, the student does not tell you what s/he would do or believes is appropriate in a situation.
3. Parameterized dynamic scenarios. To the extent reasonable, build the scenario for the next lesson based on all that is known about the student, the student's current skills deficiencies, and the student's recent learning history.

4. Imperfect conceptual models. Try to entice failure, then provide the structure (e.g., explanations of actions in context) to allow the student to engage in reflection so as to confront biased or erroneous thinking.

5. Embodied tutoring. Present a face to a tutor, potentially an avatar with the knowledge to vary characteristics such as personality and current emotion, level of 'intrusiveness', and tutoring style.

6. Augmented training. Monitor as much as is reasonable of the student, to include overt actions, her/his expressions and gestures, eye movement, affect, physiologic indicators, neurologic function, and others.

Minority Report: This proposal captures many of the ideas discussed at the Working Meeeting: reliance on experts as the "gold standard," scenario-based training and augmented (intelligent) tutoring.

Vignette #4: Leveraging Known Generalizations

The first principle is that if you want rapid and accurate performance, the trainee needs to have relevant patterns/cases highly accessible, Development of a case corpus for familiar cases can be accomplished since those cases are encountered frequently or recently. Many domains have (perceptual) features that vary in occurrence from frequent to rare but are critical to carrying out sound actions in the domain. It is relatively easy to pick up frequently occurring features/cues with most training techniques. Rare cases, by definition, occur infrequently, so one way to accelerate development of skill is to flatten the curve by presenting such cases as part of training. However, the "shape" of the task environment becomes important here. If rare cases don't have important consequences, but frequent cases do, it is not worth investing a lot of effort in training rare cases compared to more frequent (important) ones. Power law learning means that each increment in skill demands a log unit of investment/practice. Again, the shape of the task environment becomes critical given the law of diminishing returns for training (another way to phrase power law learning). I'm assuming that training cost is constant per unit (hr.) of training. So, training efforts need to focus on getting someone up to speed and then after they reach, say, journeyman skill levels, to maintaining performance via refresher training to ensure that recency can work its magic for rapid access.

Minority Report: This vignette captures additional ideas discussed at the Working Meeting, including the need for a case corpus. This vignette also points to domains where perceptual learning is critical. Especially salient is the idea of accelerating learning by accelerating the specific part of the proficiency continuum leading up to the journeyman level.

5.7.2 Research Opportunity: Rapidized Training

It might be possible to establish a research project in collaboration with one or more of the current DoD efforts at rapidized training, such as the Air Force Weather Agency's "Forecast Ready" program (McNulty, 2005) and "Cadre Focus" program (Smith, 2006), and the "Think Like a Commander" program. The 7th Weather Squadron's "Cadre Focus" initiative can be seen as following the model of the Army's National Training Center. Its focus is on making sure that forecasters are tactically and technically prepared prior to actual deployment. The method is to site students at a large training area for a week of instructions (vehicle maintenance, generator maintenance, simulated convoy operations, etc.) and experience with command and control procedures, in addition to practice at tactical meteorological forecasting.

It might be possible to establish a collaboration with the U. S. Army Corps of Engineers. The 249th Engineer Battalion, based at Ft. Belvoir VA, provides power generation for all of the U.S. Army. Although the U.S. Air Force has its own construction-power generation specialist group, the Army Battalion also works with them. It has about 200 specialists in a number of areas (e.g., generation, instrumentation, electronics). The Battalion supports a Civil Engineer Maintenance, Inspection and Repair Team that is capable of installing and operating commercial-grade power generation facilities (e.g., in support of airfields and base camps). (They also oversee the work of commercial contractors who install and operate larger-scale power systems.)

Most of the specialists are regarded as experts, though naturally the Battalion has trainees at various levels of skill and knowledge. The schoolhouse training is 1.4 years, with high math skill as a selection criterion. Once at the Battalion, there is significant mentoring on various power generation systems, increasing the complexity using a "crawl-walk-run" model. Lore is that it takes three to five years for a person to become a journeyman and ten or more years to become regarded as a master electrician. The Battalion Command desires to have half of its personnel complement at the expert level of proficiency.

Although specialists generally work in their specialty area throughout their career, there are hiatus assignments (recruiting, doctrine, etc.). On occasion up to one-fourth of the complement of specialists is on assignment, but the assignments involve power generation and distribution issues (e.g., providing back-up emergency power). Lore is that it takes up to three months to "get back up to speed" following a shorter hiatus of a year or so. Hiatus assignments of longer periods (three years) are not unheard of, but are infrequent. There has been no formal study of hiatus effects. Also hearkening to the Air Force experience, workload during hiatus assignments is such that it would be difficult for the specialist to maintain currency (i.e., aware of the latest changes in power technology and Army power systems and procedures). The Battalion does host a web site, which could assist in knowledge sharing of lessons learned. The Command is open to collaboration to research new and non-traditional methods. Chief of Engineers General Robert L. Van Antwerp has discussed the Corps's level of risk at loss of expertise, mirroring the knowledge management issue faced by many other domains and organizations.

5.7.3 Research Challenge: Methodology for Identifying Expert Mentors

We have a good idea of the characteristics of good mentors (Hoffman, 1998): Klein, 1998; Fiore & Salas, 2008; Mistrell, 1999; Proctor & Vu, 2006 (see also Section 2.3.5 above). There is often motivation of experienced workers to pass along their "tough case" knowledge, but they are typically left not knowing how to proceed, or not even knowing that their "tough case" knowledge is critical and highly constructive to apprentices.

The expert mentor can play an active role not only in on the job learning, but in guided learning as would take place in simulation-based training episodes. This could be implemented with simulation-based environments of the sort that have been discussed in this Report (i.e., Collins, Brown, & Newman, 1989; Schaper & Sonnentag, 1998).

Given the critical role of the mentor, and the potential for mentoring to promote advancement in proficiency, efforts at acceleration would be supported in a significant way by the development of a method for rapidly identifying individuals within a domain who are great mentors. We know how to go about and cognitive task analysis to reveal their mentoring reasoning strategies, including strategies for dealing with challenging mentoring situations. But there is currently no generally applicable and robust method for entering into a domain and rapidly identifying who is, and who might become, a good mentor.

5.7.4 Research Concept: Compression of Experience

It is well known that extensive experience with challenging cases and deliberate practice (and guidance) are hallmarks of the development of expertise. One likely reason for the "10,000 hours" guideline for the development of expertise is that ordinary work flow does not provide enough exposure to "tough cases," those that stretch skill, and does not present them within any kind of logical structure for learning. Finding ways to compact experiences will be vital to any program aiming to accelerate expertise. Methods might include games, simulations, virtual worlds, decision-making exercises, and other kinds of case-oriented delivery systems (e.g., Spiro, Thota, & Feltovich, 2003).

Compression would be achieved because the naturally occurring time lags and gaps between cases that afford learning opportunities could be "designed out." The caution is that experience of multiple difficult cases in an artificially compressed time period might contribute to fatigue and other negative affects. Oh the other hand, some jobs entail stress and fatigue so this might be less of a factor.

Tough and rare cases can also be used in unlearning, to reveal knowledge shields and help trainees overcome "dimensions of difficulty" within cases (Feltovich et al., 1997). In particular, the learner must be constantly stretching his or her skill, going beyond the current level of comfortable competence. Rare cases would be juxtaposed with some routine or typical cases in such a way that the learner can experience the differences that produce difficulties. Another application involves the fact that the sociotechnical workplace is constantly changing (Hoffman & Elm, 2006). New technologies, and the work methods that they shape, typically have to be integrated with legacy work methods and technologies. Conceptually, this can be viewed as a set of scenarios for practice at adaptation, not merely to handle familiar and routine cases, but to "stretch" the new technologies and work methods through application in tough cases.

If one accepts the finding from studies of experts that ten years is a lower limit, and that a lengthy period of practice with zeal is necessary, then the best that organizations could hope for is to "pre-burn" some few of the years during the novice-to-apprentice and apprentice-to-journeyman spans of training. As is shown in Figure 5.1, this would accelerate the "front end" of the learning curve that occurs prior to the long ramp in the high proficiency range. We need not be trapped by the "10,000 hour clock" if the focus were on accelerating proficiency between the apprentice and journeyman levels.
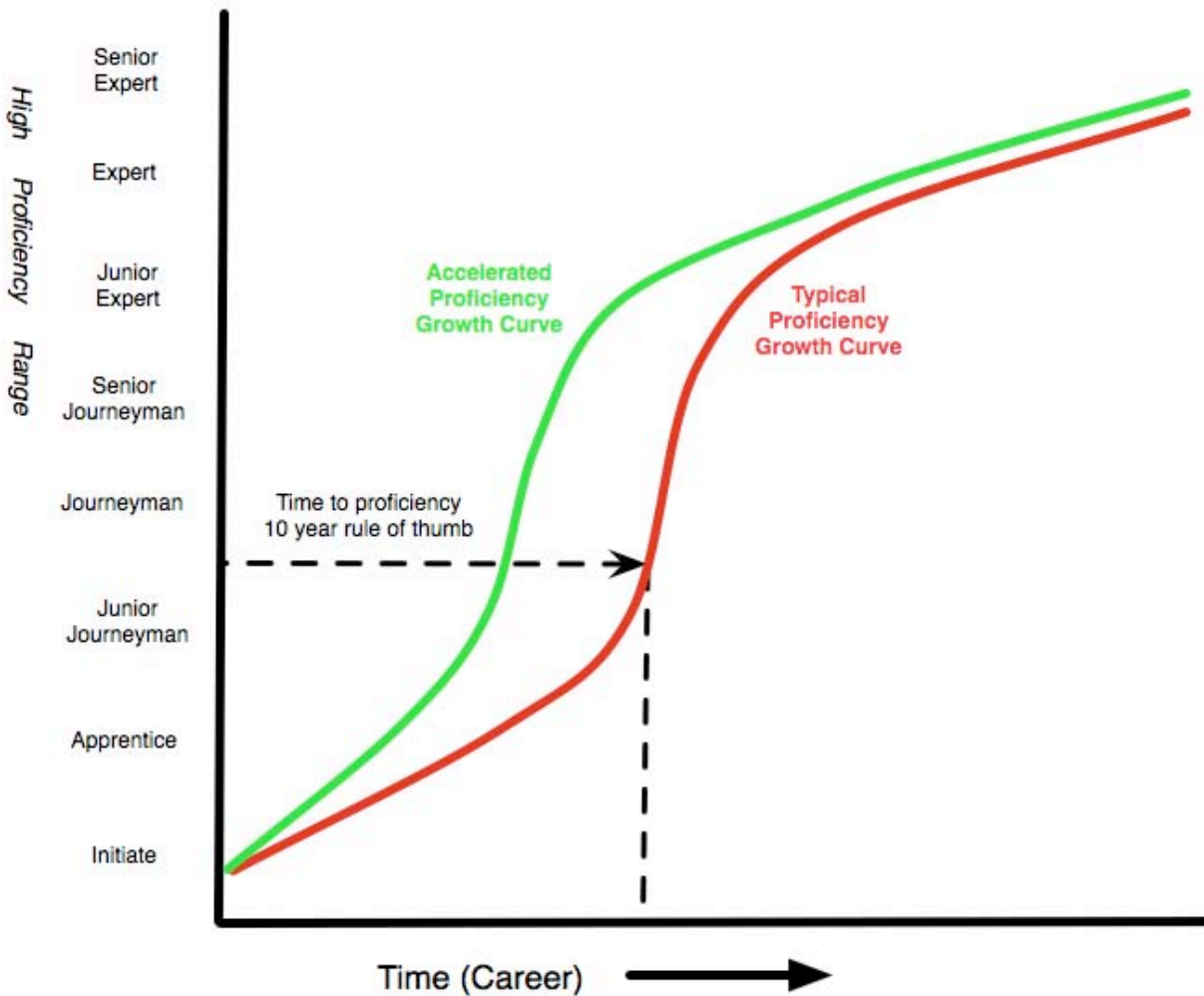
Figure 5.1. Possible proficiency achievement and acceleration curves.

Let's say the red curve represents the learning trajectory for some domain. In the red curve it takes nearly 50% of the overall learning time to reach journeyman status in that domain. A notional large leap occurs during the apprentice-to-senior journeyman range stage. And there is a long ramp, as many researchers in the field of Expertise Studies have surmised. The green curve is one where some intervention is introduced (e.g., time compressed, simulation-based training). Here it takes approximately a third of the overall learning time to reach high proficiency status. But the long ramp is still present and what's happened is that the leap in proficiency has occurred earlier.

Given the value of high proficiency, and the increasing value of high proficiency in emerging, dynamic and complex domains, if any time could be shaved off the "10,000 clock," there would be a potentially significant savings of time, an increase in overall organizational capability, and perhaps also an increase in organizational adaptability.

An initial project would have to gauge the time compression effects themselves. Since it is well established that development of skill in any complex domain takes a very long time, we are particularly interested in seeing if practice at tough cases can help accelerate the development of high proficiency, spanning the senior apprentice to senior journeyman levels. Thus, performance at the tough case tasks will have to be studied in a short-term longitudinal design. We will compare performance at tough task cases for individuals who receive multiple practice sessions over time, to individuals who are sampled across time/proficiency level, in an effort to determine if practice has a "time compression" effect. This will be gauged in light of performance at cases that are routine.

5.7.5 Study Design

We conclude by considering the design of research projects that would contribute to attempts to accelerate accelerated learning, likely focusing on the progression for journeyman to senior journeyman, or from senior journeyman to junior expert. In their book *Surpassing Ourselves*, Carl Bereiter and Marlene Scardamalia (1993) note the necessity for studying the acquisition of proficiency longitudinally, and also note the difficulties of doing that:

> The ten years or so of training and experience that typically go into the making of an expert pose a serious obstacle to research on the acquisition of expertise. The obvious kind of research to do is longitudinal and prospective: Follow a large group... through their early years of practice, collecting data that could later be analyzed for clues as to why some achieve high levels of expertise while others become experienced non-experts. But no one funds research of that duration anymore. And it would have to be intensive research, tracking people in the course of their work. Merely giving batteries of tests and correlating scores with later performance might yield findings useful for screening candidates, but it could not be expected to add much to our understanding or to leads for improving the education and nurturance of experts (p. 155).

Cohort-select designs will study multiple groups, each of which has members that fall at a proficiency level: junior apprentice, apprentice, senior apprentice, junior journeyman, journeyman, senior journeyman, and junior expert. (As explained previously, the focus would not be on expertise per se, but participation by experts would be critical to the creation of both proficiency scales and training materials.) Each of the groups is tracked across time. Proficiency scaling would identify individuals who learn fast and slow. Retrospective analyses would seek to find out why. One could identify the top performers at each proficiency level (test scores, records of past performance during training) and work backwards to find the success factors. One could study acquisition retrospectively and study degradation and retraining prospectively and thereby "cover" more of the proficiency span than the five to eight year duration of the research project itself.

Suggestions for acceleration methods, as discussed previously in this Report, include leveraging the important features of deliberate practice and mentoring, the technologies of virtual reality

training, multi-media for training at complex tasks, and leveraging computer technology to develop libraries of representative and tough tasks and knowledge bases that capture expert knowledge and skill.

Proficiency scaling conducted as a part of a longitudinal study might also contribute to selection. Bereiter and Marlene Scardamalia (1993) noted that the practice habits and learning strategies that culminate in the achievement of high levels of proficiency are not just characteristics of experts, but are also the characteristics of trainees who will eventually become experts.

> Lacking long-term research that follows the same people from novicehood to mature status, we are left having to look for plausible resemblances or parallels between what may be observed among students and what is known about experts. It is therefore a matter of considerable note that students can be found who already resemble experts in important respects. Case studies provide no basis for estimating how numerous such students are, but the fact that they exist at all should give us something to ponder (pp. 154-155).

The government sponsor of this work could ground the research program in a challenge problem (assuming the potential diversity of stakeholders permits this). That challenge problem should specify a domain or criteria for selection of a domain, a statement of the desired operational objectives, and related measures of performance for assessing research (though not necessarily performance thresholds). Research efforts should focus on approaches that enable DoD to specify a balance between accelerating acquisition and facilitating retention. Research should be presented at semi-annual sponsor-hosted workshops. These workshops should evolve in topic from description of research methods, to reports of results, and finally to presentation of technology or materials that enable DoD or its performers to implement the research or training methods in new domains.

The sections 5.1 through 5.7 of this Report presented recommendations concerning the study of: (1) Measures and levels of proficiency, (2) Selection and scaffolding for expertise development. (3) Mentoring and apprenticeship, (4) Practice and experience compression, (5) Learning for flexibility, adaptability, and resilience, (6) Procedures to improve retention, and (7) All of these factors in the context of teams and groups. Based on these recommendations, it is possible to formulate a roadmap for investigations in accelerated proficiency and facilitated retention. Such a roadmap would refer to all of the meanings of accelerated learning:

1) How to quicken the training process while maintaining its effectiveness (*Rapidized Training*),
2) How to rapidize the transposition of lessons learned from the battlespace into the training context (*Rapidized Knowledge Sharing*),
3) How to train and train quickly to higher levels of proficiency (*Accelerated Proficiency*), and
4) How to insure that training has a stable and lasting effect (*Facilitated Retention*).

A notional roadmap is presented in Figure 5.2. This timeline lays out, over months/years, a sequenced set of research activities for demonstrating accelerated learning and facilitating long-term retention. Proposals to conduct studies would start from this high-level roadmap and forge a detailed program description,, taking into account the chosen domain(s), opportunities, practical constraints and considerations. Planning details would morph as the project is constrained.

Figure 5.2 A notional roadmap for studies on accelerated proficiency and facilitated retention (page following).

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7	
	6	12	18	24	30	36	42	48	54	60	66	72	78	84
Methodological Foundation and Requirements														
Select domains and establish links with domain organizations and cohorts of practitioners	X	X												
Integrate with the training community in the selected domain	X	X	X	X	X	X	X	X	X	X	X	X		X
Career interviews, performance measures, and sociometry for proficiency scaling		X	X											
Documentation analysis (i.e., SOP documents, task analyses, syllabi) to generate normative models of reasoning and models of knowledge	X	X												
Cognitive Task Analysis to generate models of reasoning and models of knowledge	X	X	X											
Cognitive Task Analysis to generate case corpus	X	X												
Leverage Cognitive Task Analysis to generate measures and metrics for performance		X												
Identify and study journeyman/expert mentors		X	X	X	X	X	X							
Retrospective Study														
Identify cohort of experts and retired experts		X	X											
Career analyses to track performance and learning gains		X	X											

Table continues

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7	
	6	12	18	24	30	36	42	48	54	60	66	72	78	84
Accelerated Proficiency														
Refine the "cohort-select" experimental design	▨	▨												
Refine the plan for the training and testing protocols		▨												
Planning to integrate the research activities with the current training in the domain		▨												
Design of training methods/exercises (e.g., Time Compression, OPSIM, DMX, etc.) (see Section 5)		▨												
Identify control and experimental cohorts		▨												
Baseline performance		▨												
Conduct prospective study			▨	▨	▨	▨	▨	▨						
Tests for robustness, resilience, adaptivity			▨				▨							
Evaluate and integrate results								▨	▨		▩			▩

▩	Optional tracking to verify proficiency achievement level

Table continues

	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7	
	6	12	18	24	30	36	42	48	54	60	66	72	78	84
Facilitated Retention														
Develop measures for decay and retention effects		▓												
Design of maintenance/refresher training methods		▓	▓											
Design modules/exercises		▓	▓											
Refine the experimental design (control and hiatus groups)		▓												
Identify cohorts		▓												
Baseline performance			▓											
Train to criterion				▓										
Test					▓							▓		
Hiatus period (straddled groups) and experience tracking						▓	▓	▓	▓	▓	▓			
Evaluate and Integrate													▓	▓

The paramount goals of a research program would be (1) Facilitating the achievement of high proficiency, especially accelerating across the Apprentice to Senior Journeyman levels of proficiency, (2) Facilitating the retention of expertise in the form of both personnel capabilities and in the form of organizational knowledge, and (3) Producing applications for military domains including USAF mission-critical specializations.

5.7.6. Program Structure and Funding

The Roadmap presented in Figure 5.2 is designed so as to not be overly-constraining and leave open a variety of possibilities for sponsorship, program structure, funding, and proposal requirements. For instance, a research project on acceleration might be integrated with a project on retention, or the two might be separate projects.

The following factors will be formative of a program:
1). Both research topics (acceleration and retention) entail longitudinal designs and are necessarily mid-term to long-term.
2). Both research topics entail a requirement for a multi-service and multi-disciplinary research team (see Section 5.1),
3). Both research topics should involve the study of more than one domain; ideally domains that are interestingly and substantively different.

One distinct and appropriate program structure would be the Multidisciplinary University Research Initiative (MURI). Partners would include university researchers with a specialization in expertise studies and simulation/scenario design, private sector partners with a capability in cognitive systems engineering, and private sector partners with a track record of successful delivery of training material and protocols to the DoD.

To be successful, such a program would have to be adequately funded, likely in the $10M+ range. A promising course of action would be for the research projects to select domains that are of interest and importance in more than one branch of the military (see Section 5.3, above). In this way, the funding burden could be shared.

It is crucial for policy makers to appreciate the potential long-term benefits of successful demonstration of accelerated proficiency and facilitated retention. Consider the following:

- Suppose there is a military job having an existing cohort of 100 workers.
- Suppose further that in order for each worker to qualify they must go through two years of schoolhouse training.
- Suppose that in order to achieve proficiency at the journeyman level (capable of solving routine problems with no need of supervision or assistance) they must have at least 3 years of experience post-schoolhouse, and that in order to achieve the junior expert level (capable of innovation and adaptation, and able to solve rare and unusual cases on their own) they must have at least 5 years of experience post schoolhouse.
- Suppose that each worker achieves a rating having an annual salary in the range of $75,000 (Paygrades E-8, W-3, O-3; <20 years of service) to $95,000 (Paygrades E-8, W-

> 3, O-3; >20 years of service), there would be a total salary range of $7,500,000 to $9,000,000.
> - Suppose further that a higher level of proficiency (i.e., senior journeyman) could be achieved in 1.5 to 2 fewer years.
> - The net savings of two years could total $15M to $28M.

Even assuming that the faster achievement of higher proficiency would lead to increased pay grades over those years of service, the savings could potentially be enormous, and at the same time the acceleration would provide the military with a workforce that is overall of a higher level of proficiency.

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APPENDIX A

WORKING MEETING AGENDA AND ROSTER

Accelerated Learning Workshop

October 9 & 10, 2009

Working Meeting

Issues and Strategies for Accelerated Learning and the Retention of Proficiency

Workshop Sponsor: USAF Air Force Research Laboratory
711th Human Performance Division

Welcome to the Workshop!

We seem to have struck upon a topic that is not only important to our nation but also raises important scientific questions.

Our topic is the general area of skill acquisition at the "high end" of journeymen and experts. We define 'skill' very broadly to include skills of performance, knowledge, and reasoning, in diverse domains and jobs.

The scientific literatures have provided ideas about proficiency scaling. However, there have been no longitudinal examinations that would be of the scale and scope required for the understanding of the development of high levels of proficiency.

The literature on learning is vase, and includes many studies of retention, i.e., retention of a second language after some period of years. But we find no studies examining retention of high-end job performance skills and knowledge.

In the general area of retention, little attention has been given to what happens when a proficient worker has to spend some period of time on hiatus.

Issues of long-term retention seem to be a ripe area for scientific inquiry.

All of these research gaps converge on current national issues of workforce. In particular, many knowledge-based organizations, including entire sectors of the economy, are at risk due to the potential loss of expertise.

Thus, we seem to have a "tiger by the tail."

In the discussions we will have at this Workshop, we hope to spend most of our time in collegial debate moving toward these goals:

1. Identify the most important challenge questions,
2. Situate those questions in the study of domains that are important to both the government and the private sector, and
3. Roadmap one or more projects to study longitudinal skill acquisition and retention.

Thank you for agreeing to participate!

Dr. Dee Andrews   Dr. Robert Hoffman   Dr. Paul Feltovich

Table Of Contents

Workshop Guidelines

Workshop Rules of Order

- ❖ Cell phones – please set to OFF or vibrate (and vibrate, only if the vibrate mode is silent).
- ❖ We will break for email checks and phone checks. We understand that everyone is busy and has current obligations and responsibilities.
- ❖ In the group discussions, please have only one conversation at a time.
- ❖ Please be sure to express all the points that you feel a need to make.
- ❖ Please raise any questions that you feel the group might be missing.

Break-Out Group Process

- ❖ The goal of these sessions is to capture challenge problems that will inform a research roadmap. In order to produce the best results, we ask that you please adhere to the following instructions:
- ❖ Follow the guidance of your Group's facilitator;
- ❖ If your Group gets into a mode of "idea generation," please try to withhold criticism during that idea generation phase;
- ❖ Please write down every idea you have on a Post-It Note;
- ❖ Please write down every challenge question you think of on a Post-It Note;
- ❖ Please write large and legibly;
- ❖ Following idea generation, group and filter your ideas;
    - ❖ If you have generated ideas for a roadmap, try to timeline it (near-term, mid-term, long-term) and capture any SWOT that might come to mind (feasibility, start date, duration, resource requirements, etc…).

Agenda

Friday October 9, 2009

8:00 a.m.	Continental Breakfast and A.M. Beverage Service
8:45 a.m.	**Welcome** Introductions and "**Lightning Round**" • Each participant conveys their focus area and their key ideas or hot buttons on issues of training, transfer and retention.

9:45 a.m.	**Presentation 1** **Dr. Dee Andrews,** AFRL *Identifying Interesting and Viable Research Challenge Questions About Acceleration and Retention*
	    • Military Environment
	    • Long-Term Retention Study
	    • Program Roadmapping
	    • DoD Accelerated Learning Study

10:15 a.m.	**Full Group Discussion**
10:30 a.m.	**Break**
10:45 a.m.	**Presentation 2** **Dr. Paul Feltovich and Dr. Robert Hoffman,** IHMC *Acceleration and Retention: Research and Theory*
11:30 a.m.	**Presentation 3** Acceleration and Retention Issues **Lt Col Gina Hilger,** USAF *Intelligence-Surveillance, Reconnaissance Requirements*
12:15 p.m.	**Lunch** *in the Garden Pavilion*
1:15 p.m.	**Presentation 4** Acceleration and Retention Issues **David Ziebell** (EPRI) *Infrastructure and Power Distribution Domains*
2:00 p.m.	**Full Group Discussion**
2:15 p.m.	**Presentation 5** Acceleration and Retention Issues **Col Daniel Walker**, USAF-AFRL *UAV Operations*
3:00 p.m.	**Break**
3:15 p.m.	**Break-Out Groups** (3) • Selection of Domains
4:45 p.m.	**Break**
5:00 p.m.	**Full Group Discussion** • Research Design and Methodology Considerations • Closing comments and look ahead at Agenda for Day 2
7:00 p.m.	***Group Dinner at Rancho de Tia Rosa's***

Agenda

October 10, 2009

8:30 a.m.	Continental Breakfast and A.M. Beverage Service
9:15 a.m.	(Re)framing based on Day 1 results
9:30 a.m.	**Presentation 6** Acceleration and Retention Issues **Lt Col Doyle Turner,** USAF *Pilot Transition Training*
10:00 a.m.	**Break**
10:15 a.m.	**Break-Out Groups** (3) • Selection of Domains • Research Design and Methodology Considerations
11:15 a.m.	**Break**
11:30 a.m.	**Presentation 7** Acceleration and Retention Issues **Dr. Winston Bennett**, AFRL *F-16 Retention Research*
12:15 p.m.	**Lunch** *in the Garden Pavilion*
1:15 p.m.	**Presentation 8** Acceleration and Retention Issues **Dr. Kevin Gluck,** AFRL (with Dr. Tiffany Jaztrzembski) *Predictive Performance Optimizer*
1:45 p.m.	**Break-Out Groups** (3) • Challenge Questions for Research
2:30 p.m.	**Break**
2:45 p.m.	**Full Group Brainstorm** • From Challenge Questions to a Research Roadmap
3:45 p.m.	**Break**
4:00 p.m.	**Full Group Brainstorm** *continued* • From Challenge Questions to a Research Roadmap
5:00 p.m.	**Closing Discussion: Look ahead** Acknowledgements

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APPENDIX B

WHITE PAPER READ-AHEAD

"ACCELERATED LEARNING AND FACILITATED RETENTION OF PROFICIENCY"

Robert R. Hoffman, Paul Feltovich, Stephen M. Fiore, Gary Klein, Dee Andrews

Introduction

The objective of this effort is to create a design and roadmap for investigations aimed at developing robust and broadly-applicable methods for:

(1) Accelerating the achievement of proficiency in USAF mission-critical specializations (and analogous domains in the private sector), and

(2) Facilitating the retention of knowledge and skill, especially for military personnel who must take long hiatuses from their domain of primary expertise in order to fulfill other military requirements.

USAF personnel, especially officers, are required to leave those domains to perform duties such as staff duty, teaching at a military academy or in Reserve Officer Training Corps programs, and taking courses of study at military or civilian institutions of higher education. These hiatuses can last from a few weeks to as long as four years. During these hiatuses it often not possible to train or practice in their domain of primary expertise.

Proficiency is critical to performance in complex work contexts, including the transformed strategic environment that confronts the USAF. During the Cold War, USAF personnel could typically count on staying in one place for assignment for at least three years before rotating. That era allowed for robust continuous training while at a duty station. However, in this current era of frequent deployments to a variety of locations worldwide to fight the War on Terror, there are far fewer opportunities to have systematic training and practice. Yet, it still ordinarily takes many years to achieve proficiency. Therefore, there would be great advantages if the USAF could establish regimens of training that could accelerate the achievement of that proficiency. There is reason to hypothesize that the achievement of proficiency can be accelerated, and the proposed working meeting will generate specific plans and roadmaps for actual attempts to do so. It is likely that methods for acceleration will leverage the technologies and capabilities including virtual training, cross training, training across strategic and tactical levels, and training for resilience and adaptivity.

The proposed working meeting would enable and support a larger-scale effort to culminate in a robust and broadly-pplicable suite of methods for facilitating the achievement and retention of proficiency.

Background

A workshop sponsored by the Office of the Director, Defense Research and Engineering and the DoD Accelerated Learning (AL) Technology Focus Team (July 2008) brought together leading academic, private sector, and DoD specialists in areas of training and expertise studies,

to discuss the goal of accelerated learning. Presentations at that workshop laid out the major challenges and issues for accelerated learning, and the activities proposed here will extend and refine the results of that effort, along with an initial "road-map" for investigations in mission-critical areas of the Air Force. In addition, the challenge of competency retention for personnel taking hiatuses will be explored.

While many military jobs can be trained through established COTS methods, and those tasks can be performed by journeymen, the military needs highly proficient personnel who can perform tasks. The bottleneck for producing such critical individuals is that it has typically taken many years of experience and deliberate practice for individuals to master their domains (e.g., anti-submarine warfare; see Ericsson et al., 2006). Reasons for this include domain complexity, irregularity across encountered cases, the need for deliberate practice, and the need for practice at tough cases to stretch skill.

Domain specialists provide technical judgment to speed decision-making in time-critical events. They provide resilience to operations by resolving tough problems, anticipating future demands and re-planning, and acting prudently by judgment rather than by rule. Specialists exercise effective technical leadership in ambiguous or complex situations, often by communicating subtle features that other people will not see until they are pointed out (Hoffman, 1997). Often they are also the ones who understand the history, the interdependencies of units and processes, and the culture of their complex organizations, knowledge that is often essential in actually "getting things done" (e.g., Stein, 1997).

The challenge of learning is compounded in the military by such practices as collateral assignment, frequent redeployment (e.g., rapid skill decay on the part of pilots creates a need for expensive re-training), inadequate or ad hoc mentoring, and the drive for "just-in-time" training. Another significant challenge is clustered around career (versus job) training, and expertise retention. Professional Military Education offered by such intuitions as the various war colleges is an example of career training. There personnel learn about operational and strategic warfighting issues. Indeed, the entire field of "knowledge management" is formed around the notion of preserving and sharing expertise (e.g., Becerra-Fernandez, et al., 2004).

Transfer, or the ability to use knowledge flexibly and effectively across application areas, is an important component of proficiency. In large respect, accelerated learning means improving transfer (and retention) capability. The major theory of transfer in learning is the "common elements" theory. Based on this idea, one would say that training should minimize the transfer distance from training to workplace. Recent research is suggestive of the conditions that promote transfer, such as the judicious use of particular kinds of feedback (Schmidt and Bjork, 1992). For instance, summary feedback is less conducive of initial learning than feedback after each trial, but summary feedback during learning does seem to promote delayed retention.

Performance issues go beyond transfer from the classroom to the operational context. Simply "working at a job" does not promote progression along the proficiency continuum (e.g., Feltovich, Prietula, and Ericsson, 2006). Unless there is continuous deliberate practice and feedback at difficult tasks, the only thing one can do "on the job" is forget and actually experience degradation of skill.

Furthermore, the current challenges for military training involve two different sorts of transfer. One is *transfer across mission types.* An example would be an infantry commander, who knows traditional warfare, who is asked to develop tactics for an insurgency operation. The second challenge is transfer across responsibilities. An example would be a warfighter having a skill at maintenance of an F-16 engine who is promoted to a supervisory position. Since different skill sets would be involved, one would need to train for the new role, and not just assume transfer would or might happen. When a journeyman or expert moves from a job where domain expertise is all that is required of them to a supervisory job, there is extra challenge because they are still expected to maintain their domain competence while also acquiring and performing their new supervisory skills.

The 2008 Workshop successfully pointed to capability gaps. The challenge now is how to a structure research questions and a research strategy to help the military address the gaps. Suggestions for acceleration methods include leveraging:
- The important features of deliberate practice and mentoring,
- The technologies of virtual reality training,
- Multi-media for training at complex tasks,
- Computer technology to develop and manage libraries of representative and tough tasks,
- Computer technology to develop and manage knowledge bases that capture expert knowledge and skill, and
- New cognitively based methods for designing instruction.

The technical research community is now positioned to work specifically on the question of how to create robust methods to accelerate the achievement of proficiency and facilitate its retention. Such objectives are the focus for a follow-on Working Meeting on Accelerated Learning and retention of competency that is the core component of the project we are proposing.

Retention Issues

An important part of the workshop is devoted to the reacquisition and retention of competence we relate below some key principles of learning retention. These principles from the literature are key for understanding retention for short term hiatuses from the domain of interest (e.g., weeks or months). However, there is very little literature and even less data about the types of long term hiatuses (up to four years) that many military personnel face. How to research such longitudinal situations will be a major focus of the workshop.

Active Versus Passive Learning
Retention of knowledge and skill is better when material at the time of acquisition is processed deeply, embellished, and connected to and integrated with other knowledge – in general, when knowledge is not compartmentalized, but is richly structured and indexed. Material to be learned is actively manipulated, rather than being merely repeated in learning. Manipulations supporting active learning may include extrapolating, discussing, Concept Mapping, alternative perspective

taking, practicing on related problems and cases, creating related projects, and so forth (Bransford, Brown and Cocking, 2000; see also Canas, et al., 2003).

Tapping the Deep Structure and Developing Rich Understanding
Retention of knowledge and skill is better when complex material is "understood," rather than learned by rote; when concepts principles, and rules complement or supplement teaching of rote knowledge or facts. Novices approach complex problems much differently from experts. Novices code problems in term of their surface features (e.g., the objects involved) and try to link (meager) solutions to these interpretations, which in most complex fields cannot support rich problem solving. Experts, in turn, understand problems, by encoding their "deep" structure, often functional, integrated relationships that can be functionally tied to solutions (Chi, Feltovich and Glaser, 1981). These deep structures are abstract, and hence support both transfer and retention (Zeitz, 1997).

Redundant Indexing, Multiple Representations
A fact of our modern world is change and diversity. People are expected to have multiple jobs over a career, jobs themselves change, customization is required, work tools change, technology encroaches, and so forth. Knowledge and skills that will need to be used in many ways must be practiced in many ways, construed in many ways, connected and indexed in many ways, and represented in many ways (e.g., Spiro, et al., 1992, Spiro, Thota, Collins and Feltovich, 2004). This affects retention by supporting redundant indexing, cross-case connectivity, and cognitive flexibility in dealing with novel instances over time. (Spiro, et al., 1988).

Understanding Concepts in Context and Making Fine Discriminations
Experts develop vast memory, organized for finely tuned cases and case-elements within their field of mastery (Ericsson et. al., 2006). This helps them finely discriminate case elements as indexes for just the right structure(s) in memory. Well-tuned case structure memories enable better indexing, anticipation of "what's next," and understanding of when an initially triggered model for interpretation is ill-suited (i.e., has gone down the wrong path) (Feltovich, Spiro, & Coulson, 1997). This affects retention in that it is important that the *right* information is recalled flexibly over time.

Cognitive Transformation and Undoing Bad Learning
Unfortunately, it has been found that in areas of learning that are difficult, learners can develop highly engrained, overly simplistic misconceptions that can impede greater understanding over time. This affects retention in that, even with long-term practice, it is *wrong* understandings that are being reinforced, maintained. Methods of instruction based on Cognitive Transformation Theory (Klein and Baxter, 2009), and Cognitive Flexibility Theory (Spiro, et al., 1988) are aimed at undermining faulty conceptions (as well as supporting the development of better ones).

Practice and Continuous Learning
Clearly, the best means for retaining knowledge and skills is to never stop practicing and learning. This is the bedrock of expertise research, reflected in the concept of life-long "deliberate practice" (Ericsson et al., 2006). It has even been shown that, for experts, knowledge and skills directly from their field of expertise are the last to degrade with the advent of age-related dementia, perhaps the ultimate retention (e.g., Krampe and Charness, 2006).

Transfer-Appropriate Processing
Retention is more effective when conditions of training and learning resemble those in which the learned knowledge and skill will be applied. This condition for retention and transfer is complicated in ill-structured domains, where there can be special demands for knowledge transfer that result from the likely variability between conditions of initial learning and later use. This accentuates the need for training that uses multiple cases, multiple perspectives, and multiple goals for knowledge use in the course of learning.

Focal Points for the Working Meeting

The following core topics will be addressed.

Measures and Levels of Proficiency
This topic addresses the measurement methodology to determine levels of proficiency. This needs to go beyond the traditional rough cuts often used in organizations and expertise studies (i.e., expert versus novice) to achieve finer discriminations along the skill continuum (e.g., Hoffman, 1998). The challenge is to establish reliable and valid markers that might be used for such things as placement, promotions, and for use in assigning practitioners to skill levels in research studies. In this regard, measurement of performance for all complex sociotechnical systems must also go well beyond traditional measures of the performance of individuals (hits, errors, rate, etc.) (Alberts and Hayes, 2003).

Selection and Scaffolding for Development
Traditional hiring practices have not served well to predict who will eventually be a high performer. New methods need to be investigated. For instance, it may be that common screening tools at hiring will need to be replaced or augmented by various indicators that only become apparent after some period of time functioning on the job. Along with identification, there will need to be programs for supporting progressive development beyond what are typically taken to be "professional development" activities in many organizations.

Mentoring and Apprenticeship
Many aspects of work are best learned "at the bench," under guidance from a skilled mentor. These include what is often called "tacit knowledge," that is, many aspects of "know how," where opportunities for learning largely manifest themselves in the course of real, active work, in the social context of work (Schön, 1983). We need to be able to identify excellent mentors, study them to reveal the knowledge and strategies of mentors, and develop programs for training mentors. We also need to determine what job practices are best suited for mentoring, as opposed to using other kinds of training techniques.

Practice and Experience Compression
It is well known that extensive experience with challenging cases and deliberate practice (and guidance) are hallmarks of the development of expertise. One likely reason for the "10,000 hours" guideline for the development of expertise is that ordinary work flow does not provide enough exposure to "tough cases," those that stretch skill, and does not present them within any

kind of logical structure for learning. Finding ways to compact experiences will be vital to any program aiming to accelerate expertise. Methods might include games, simulations, virtual worlds, decision-making exercises, and other kinds of case-oriented delivery systems (e.g., Spiro, Thota, and Feltovich, 2003).

Scaling Cases

Experience with cases is critical to the development of expertise, as is compression of these experiences. Research to reliably test degree of learning, retention, and adaptation, will need a set of dependable scenarios or cases that can be scaled for difficulty, and that span a range of situations. Well-known knowledge elicitation methods (e.g., the Critical Decision Method; Crandall, Klein and Hoffman, 2006) can be employed, with participants who span the proficiency scale (i.e., novice, apprentice, journeyman, expert) to elicit cases. Hence, it will be necessary to develop a large case repository in which cases are scaled for difficulty relative to the different levels of proficiency. For each level we will need cases that are fairly ordinary at that level, but also "level stretchers"— tough cases that push capability beyond the current rank. Such a case library can be used in training, evaluation, and research projects.

Designing Case Libraries

Case experience is so important to expertise that it can be envisioned that organizations will develop very large case repositories for use in training, but also to preserve organizational memory. Instruction using cases is greatly enhanced when "just the right case" or set of cases can be engaged at a prime learning moment for a learner (Kolodner, 1993). (This also argues for large numbers of cases, to cover many contingencies) This is a matter of organization among cases, good retrieval schemes, and smart indexing. Note that an added benefit from the creation of case repositories is that the process of developing cases is itself a form of knowledge elicitation, and therefore it feeds directly into the process of capturing expert knowledge.

Learning for Flexibility, Adaptability, and Resilience

Robustness is the ability to maintain effectiveness across a range of tasks, situations, and conditions. Resilience is the ability to recover from a destabilizing perturbation in the work as it attempts to reach its primary goals. Adaptivity is the ability to employ multiple ways to succeed and the capacity to move seamlessly among them. Fundamental to the achievement of robustness, resilience and adaptivity is the opportunity to practice at problems that stretch current competency (Ericsson and Lehmann, 1996; Feltovich, et al., 1997). However, modern work presents challenges for achieving such adaptive skills. For much of history, individuals have developed mastery and resilience by focusing intensely on a relatively circumscribed task or suite of skills, e.g., chess or welding. Modern work (especially in sociotechnical work systems) has become much more unstable and complex. People change jobs, jobs change, orders change, technology intrudes and changes the work, customization in products and services requires versatility beyond the assembly line, etc. Can we train (or select for) expertise in flexibility and resourcefulness? What kind(s) of learning and materials does it require? For example, one method that has been used is to have workers rotate through other job roles that are integrated with their own work.

Addressing All of These Factors, and More, in the Context of Teams and Groups

In addition to fluidity, customization, etc., another prominent feature of modern work involves teams and teamwork. For functional, workable acceleration to be possible, training exercises must encourage the acquisition of teamwork skills. An expert group is not the same as a group of experts (Salas, et al., 2006). While many skills may be in common, teamwork engages others, for example, certain kinds of "people skills," coordination skills, understanding of others and their "ways," and the ability to develop and maintain satisfactory mutual understanding, "common ground" (Klein, Feltovich, Bradshaw, and Woods, 2004).

Reacquisition of Competency
As discussed above, military personnel face challenges of not only retaining competency, but also reacquiring competency once it has been degraded through non-use after long hiatuses. This phenomenon caused by perhaps years away from domains of primary competency is relatively unique to the military and has not really been studied by learning researchers. Therefore, we are left to largely wonder if principles of reacquisition that have been studied in shorter hiatuses might be applicable to the situation faced in the military, or will empirical study reveal new principles.

Specific Meeting Activities

The Working Meeting will have a focus on identifying important and difficult areas of Air Force and civilian work-practice for which it is feasible to conduct actual programs of research to accelerate and retain expertise, and to reacquire expertise once degraded or lost completely.

The Working Meeting will have a goal of generating detailed roadmaps for how one or more such research projects would be planned and conducted, including the resources and capabilities required.

Identify candidate sub-domains for analysis and focus: We will begin to identify domains that might be a focus for attempts to accelerate the achievement of expertise. We will seek mission critical areas that manifest some combination of these features:
- Hard to learn and do well, as attested to, for instance, by high wash-out rates and few extant experts;
- Have in the past required very long training and on-the-job experience;
- Demonstrate complexity in that they involve many interacting components and stakeholders; are dynamic;
- Are irregular in that different versions of the "same problem" may look very different; and Reflect complex, dynamic and nonlinear patterns of causation, and decision making under uncertainty.
- Have potential for significant cross-over applications of accelerated learning to the civilian sector and are also possible candidate domains for analysis, such as weather forecasting.

The road-mapping effort will converge on the identification of at least two (and ideally three) domains that are interestingly as well as substantively different, that are mission critical, and that depend on expertise and high levels of proficiency (see the discussion above on the

identification of candidate sub-domains. While one might seek to design and conduct a single study on acceleration, in some single selected domain, that would serve only as a demonstration and would not capitalize on the potential of the proposed working meeting. Thus, the anticipated product would include more than one roadmap for acceleration projects in more than one domain, to allow scientific comparisons and convergence.

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Hoffman, R. R. (Ed.) (2007). *Expertise out of context: Proceedings of the Sixth International Conference on Naturalistic Decision Making*. Boca Raton FL: Taylor and Francis.

Hoffman, R. R., Fiore, S. M., Klein, G. and Feltovich, P. (July, 2008). Accelerating the Achievement of Mission-Critical Expertise. Report to the Electric Power Research Institute, Palo Alto, CA.

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Spiro, R., Coulson, R., Feltovich, P., and Anderson, D. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In *Proceedings of the 10th Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Zeitz, C. M. (1997). Some concrete advantages of abstraction: How experts' representations facilitate reasoning. In P. J Feltovich, K. M. Ford and R. R. Hoffman (Eds.). *Expertise in context* (pp. 43-65). Menlo Park, CA: MIT/AAAI Press.

APPENDIX C

BIOGRAPHICAL SKETCHES OF THE WORKING MEETING PARTICIPANTS

Dee H. Andrews
U.S. Air Force

Dr. Dee H. Andrews is a Senior Scientist (ST) with the Human Effectiveness Directorate, 711th Human Performance Wing, of the Air Force Research Laboratory in Mesa, Arizona. Previously he held the position of Division Technical Director for the Warfighter Training Research Division of the Air Force Research Laboratory. He received his Ph.D. is in Instructional Systems from Florida State University. His B.S. is in Psychology from Brigham Young University. Previously he worked as a senior research psychologist for the Army Research Institute for the Behavioral and Social Sciences in Orlando, Florida. Prior to his work with the Army he was a Research Psychologist and training analyst with the Naval Air Warfare Center – Training Systems Division in Orlando, Florida. He is a Fellow in the Human Factors and Ergonomics Society, the American Psychological Association, the Royal Aeronautical Society of the United Kingdom, and the Air Force Research Laboratory. His research interests include: learning organizations, simulator design, flight training, advanced distributed learning, accelerated learning and distributed mission training.

Neil Charness
Florida State University

McGill University, Montreal, Quebec, Canada	BA	1965-1969
Carnegie Mellon University, Pittsburgh, USA	MS	1969-1971
Carnegie Mellon University, Pittsburgh, USA	PhD	1969-1974

Professional Positions
1974-1977: Assistant Professor, Wilfrid Laurier University, Canada.
1977-1993: Assistant, Associate, Full Professor, Psychology Department, University of Waterloo, Canada.
1984-85: Sabbatical Fellow, Mental Performance & Aging Laboratory, VA Outpatient Clinic, Boston
1990-91: Visiting Scholar at the Psychology Department, University of Victoria, Victoria, BC
1993 (4 mo.): Visiting Scientist, Max Planck Institute for Human Development and Education, Berlin
1994+: Professor, Psychology, Florida State University & Associate, Pepper Institute on Aging and Public Policy. William G. Chase Professor of Psychology

Editorial Appointments
Editor, Psychology section, 1985-1989. Canadian Journal on Aging/Revue Canadienne du Vieillissement.
Editorial board, 1987-1991, 2000+ Journal of Gerontology, Psychological Sciences.
Editorial board, 1987+ John Wiley & Sons: Human Performance and Cognition series.
Editorial board, 1992-2001, 2003+ Psychology and Aging.
Editorial Board: 1993-1996 Aging, Neuropsychology, and Cognition.
Editorial Board: 1994-1996 Psychological Bulletin

Editorial Board: 2001+ Gerontechnology
Editorial Board: 2007+ Journal of Experimental Psychology: Applied.

Honors
1993 Elected Fellow, Canadian Psychological Association
1994 Elected Fellow, Gerontological Society of America
1995 Elected Fellow, American Psychological Association, Division 20 (Adult Development & Aging)
1997 Elected Fellow, American Psychological Society
2008 Appointed Honorary Member, International Society of Gerontechnology.

Selected Peer-Reviewed Publications (in chronological order) (last 3 years)
Roring, R. W., Hines, F. G., & Charness, N. (2007). Age differences in identifying words in synthetic speech. *Human Factors, 49*, 25-31.
Roring, R.W. & Charness, N. (2007). A multilevel model analysis of expertise in chess across the lifespan. *Psychology and Aging, 22*, 291-299.
Jastrzembski, T. S. & Charness, N. (2007). The Model Human Processor and the older adult: Parameter estimation and validation within a mobile phone task. *Journal of Experimental Psychology: Applied, 13,* 224-248
Jastrzembski, T., & Charness, N. (2007). What older adults can teach us about designing better ballots. *Ergonomics in Design, 15*, 6-11.
Charness, N. (2008). Aging and human performance. *Human Factors, 50*, 548-555.
Charness, N., & Tuffiash, M. (2008). The role of expertise research and human factors in capturing, explaining, and producing superior performance. *Human Factors, 50*, 427-432.
Weaver, S. J., Charness, N., Dijkstra, K., & Jastrzembski, T. (2008). Musculoskeletal pain prevalence in randomly sampled university employees: Age and gender effectsGerontechnology, 7, 279-292.
Charness, N. & Boot, W. R. (in press). Aging and Information Technology Use: Potential and Barriers. *Current Directions in Psychological Science.*

Recent Books and Book Chapters
Charness, N., Czaja, S. J., & Sharit, J. (2007). Age and technology for work. In K. S. Schulz & G. A. Adams (Eds.) *Aging and work in the 21st century* (pp. 225-249). Mahwah, NJ.: Erlbaum.
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Charness, N. (2008). Technology as multiplier effect for an aging work force. In K. W. Schaie & R. Abeles (Eds.) *Social structures and aging individuals: Continuing challenges* (pp. 167-192). New York: Springer.
Charness, N., & Jastrzembski, T. S. (2009). Gerontechnology. In P. Saariluoma & H. Isomäki (Eds.). *Future Interaction Design II* (pp. 1-29), London: Springer-Verlag.
Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). Designing for older adults: Principles and creative human factors approaches (2nd Ed.). Boca Raton: CRC Press.
Charness, N. (2009). Skill acquisition in older adults: Psychological mechanisms. In S. J. Czaja & J. Sharit (Eds.). *Aging and work: Issues and implications in a changing landscape* (pp. 232-258). Baltimore: The Johns Hopkins University Press.

Paul J. Feltovich
Research Scientist at the Florida Institute for Human and Machine Cognition

He has conducted research and published on topics such as expert-novice differences in complex cognitive skills, conceptual understanding and misunderstanding for complex knowledge, and novel means of instruction in complex and ill-structured knowledge domains (Cognitive Flexibility Theory and Reductive Bias Theory--with Rand Spiro and Richard Coulson). Since joining IHMC in 2001, he has been investigating (with Jeff Bradshaw and the KAoS team) coordination, regulation, and teamwork in mixed groups of humans and intelligent software agents. These studies employ a "cultural" approach to controlling and modeling software agent activity, based on the utilization of diverse policy systems ranging from formal pertinent law, to group traditions, to standards of practice, to norms for acceptable every day behavior (e.g., various codes of etiquette). The work also addresses Human-Agent coordination in mixed teams and factors that contribute to making software agents acceptable to humans as partners in complex and consequential work. He has authored more than one hundred professional articles and three books. In particular, he is co-author (with Micki Chi and Robert Glaser) of a designated *Science Citation Classic* paper on problem solving in physics which has contributed greatly to the development of human expertise as a field of study in cognitive science. Feltovich was chosen to write one of the articles on expertise for the *Third International Encyclopedia for the Social and Behavioral Sciences*, and has recently co-edited (with Anders Ericsson, Neil Charness, & Robert Hoffman) the first ever *Cambridge Handbook on Expertise and Expert Performance.* He is also co-editor (with Ken Ford and Robert Hoffman) of *Expertise in Context: Human and Machine (*AAAI/MIT) and (with Ken Forbus) *Smart Machines in Education* (AAAI/MIT).

Stephen M. Fiore
University of Central Florida

Education

Institution	Major	Degree and Year
Montgomery College	Business Administration	A.A. 1986
University of Maryland	Marketing	B.S. 1988
University of Maryland	Psychology	B.A. 1991
University of Pittsburgh	Cognitive Psychology	M.S. 1994
University of Pittsburgh	Cognitive Psychology	Ph.D. 2000

Appointments

2007-present   Director, Cognitive Sciences Laboratory, Institute for Simulation and Training
                University of Central Florida, Orlando, FL
2005-present   Assistant Professor, Cognitive Sciences Program, Department of Philosophy,
                University of Central Florida, University of Central Florida, Orlando, FL

2002-2007	Director, Consortium for Research in Adaptive Distributed Learning Environments, Institute for Simulation and Training University of Central Florida, Orlando, FL
2000-present	Research Scientist, Team Performance Laboratory, Department of Psychology, University of Central Florida, Orlando, FL
1998-2000	Research Associate, Department of Psychology – Team Performance Laboratory, University of Central Florida, Orlando, FL
1992-1998	Lab Coordinator, Learning Research and Development Center, University of Pittsburgh, Pittsburgh, PA
1990-1992	Research Assistant, Laboratory of Socio-environmental Studies, National Institute of Mental Health, Bethesda, MD

Selected Publications

Hoffman, R. R., Feltovich, P. J., Fiore, S. M., Klein, G., & Ziebell, D. (2009). Accelerated Learning (?). *IEEE Intelligent Systems, 24(2),* 18-22.

Fiore, S. M. (2008). Interdisciplinarity as Teamwork: How the Science of Teams can inform Team Science. *Small Group Research, 39(3),* 251-277.

Fiore, S.M. & Salas, E. (2008). Cognition, Competition, and Coordination: Understanding Expertise in Sports and its Relevance to Learning and Performance in the Military. *Special Issue of Military Psychology, Volume 20, Issue S1*

Hoffman, R. R., & Fiore, S. M. (2007). Perceptual (re)learning: A leverage point for human-centered computing. *IEEE Intelligent Systems, 22, 3,* 79–83.

Fiore, S.M. & Salas, E. (2006). Team Cognition and Expert Teams: Emerging Insights into Learning and Performance for Exceptional Teams. *International Journal of Sports and Exercise Psychology, Volume 4.*

Fiore, S. M. & Salas, E. (Editors). (2007). *Toward a science of distributed learning.* Washington, DC: American Psychological Association.

Fiore, S. M., Harrison, G. W., Hughes, C. E., & Rutstrom, E. E. (2009). Virtual Experiments and Environmental Policy. *Journal of Environmental Economics & Management, 25,* 65-86.

Fidopiastis, C.M., Stapleton, C.B., Whiteside, J.D., Hughes, C.E., Fiore, S.M., Martin, G.A., Rolland, J.P. & Smith E.M. (2006). Human experience modeler: Context driven cognitive retraining to facilitate transfer of training. *Cyberpsychology & Behavior, 9, 2,* 183-187.

Cuevas, H. M., Fiore, S. M., Bowers, C. A., & Salas, E. (2004). Fostering constructive cognitive and metacognitive activity in computer-based complex task training environments. *Computers in Human Behavior, 20,* 225-241.

Fiore, S.M., Jentsch, F., & Rubinstein, J. (2004). Science and Security: Human-centered Research for Keeping our Nation Safe. Special Section of *International Journal of Cognitive Technology*, Volume 9.

Dr. J. D. Fletcher is a research staff member at the Institute for Defense Analyses where he specializes in manpower, personnel, and training issues. His graduate degrees are in computer science and educational psychology, both from Stanford University. He has held academic positions in psychology, computer science, and systems engineering and government positions as a research psychologist and/or program manager for the Navy, Army, the Defense Advanced Research Projects Agency, and the White House Office of Science and Technology Policy where he developed cross-agency plans, programs, and policies in education and training. He is a fellow of the American Educational Research Association and three divisions of the American Psychological Association. His research activities have produced intelligent[1] tutoring systems, networked simulations, wearable voice-interactive performance aids, international specifications for sharable digital objects, and cost-effectiveness analyses on the use and impact of instructional technology.

Jared Freeman, Ph.D.
Aptima, Inc.

Jared Freeman, Ph.D., is Senior Vice President of Research at Aptima. As a member of Aptima's executive team, he works to maintain the quality of Aptima's research and to coordinate research efforts within the company.

Dr. Freeman is a cognitive scientist by training with a Doctorate in Human Learning and Cognition. He investigates problem solving and decision making in real-world settings, and defines training and job aids that address these challenges. Within the past several years, Dr. Freeman has served as Aptima's Principal Investigator in research and development projects to analyze, model, train, and aid information system managers, imagery analysts, information operations specialists, technicians for intelligence equipment, warfighters engaged in anti-piracy operations at sea and peacekeeping ashore, and interagency personnel engaged in Maritime Domain Awareness missions. He also has served as P.I. on projects to integrate neuro-cognitive and behavioral measurement technologies; measure, monitor and manage team knowledge and collaboration; automate the analysis of voice communications; automate the analysis of written usability documents; and model the fit between human cognitive abilities, decision support systems, and mission requirements. His business development efforts have generated numerous contracts from research laboratories, training, and acquisition organizations for the Army, Navy, Marines, Air Force, and Joint organizations.

Prior to joining Aptima, Dr. Freeman was a scientist at Cognitive Technologies, where he developed a highly automated approach to assessing student knowledge of tactical situations, as well as instructional technology that improved situation assessment and planning by Army officers. Dr. Freeman consulted to Bell Labs for two years, where he conducted research

concerning how experts diagnose failures in complex software systems, co-developed a course based on that research, and taught it nationally.

Dr. Freeman has published more than 100 chapters, articles, and proceedings papers on the topics of critical thinking, task analysis, computational modeling of teams, performance measurement, and training.

Dr. Freeman received a Ph.D. from Columbia University and a M.A. in Educational Technology from Teachers College, Columbia University. He is a member of the Human Factors and Ergonomics Society, and a contributing editor to *Human Factors.*

Dr. Andrew S. Gibbons
Brigham Young University

Andy Gibbons is the chair of Instructional Psychology and Technology at Brigham Young University. Prior to that, he was a faculty member at Utah State University for 10 years. This followed 18 years of leading instructional design projects in industry, including work on large-scale training development, design of simulations, and innovative forms of computer-based instruction. Dr. Gibbons' research focuses on the architecture of instructional designs. He has published a design theory of Model-Centered Instruction, proposed a general Layering Theory of instructional designs, and is currently studying the use of design languages in relation to design layers to create instructional systems that are adaptive, generative, and scalable.

Waters, S. H. & Gibbons, A. S. (2004). Design languages, notation systems, and instructional technology: A case study. *Educational technology research and development*, 52(2), 57-68.

Gibbons, A. S. (2003). What and how do designers design: A theory of design structure. *Tech trends*, 47(5), 22-27.

Fairweather, P. G. & Gibbons, A. S. (2000). Distributed learning: Two steps forward, one back? One forward, two back? *IEEE Concurrency*, 8(2), 8-9+.

Gibbons, A. S., Bhardwaj, K. K., & Richards, R. (1998). The single-parse method of design for problem-based instruction. *Educational technology research and development*, 46(2), 110-116.

Gibbons, A. S., Bunderson, C. V., Olsen, J. B., & Robertson, J. (1995). Work models: still beyond instructional objectives. *Machine-mediated learning*, 5(3&4), 221-236.

Gibbons, A. S. & Rogers, P. C. (2009). The architecture of instructional theory. In C. M. Reigeluth & A. Carr-Chellman (Eds.), *Instructional-design theories and models, Volume III*. Mahwah, NJ: Lawrence Erlbaum Associates.

Gibbons, A. S., McConkie, M., Seo, K. K., & Wiley, D. (2009). Theory for the design of instructional simulations and microworlds. In C. M. Reigeluth and A. Carr-Chellman (Eds.), *Instructional-design theories and models, Volume III*. Mahwah, NJ: Lawrence Erlbaum Associates.

Gibbons, A. S. (2008). Coming at design from a different angle: Functional design. In L. Moller, J. Huett & D. Harvey (Eds.), *Learning and instructional technologies for the 21st century*. New York: Springer.

Gibbons, A. S. (2006). A model of technology capable of generating research questions. *2006 Educational technology and media yearbook*. (In conjunction with E. Boling and B. Bichelmeyer). Bloomington, IN: Association for Educational Communications and Technology. Also presented at the 2004 Association for Educational Communications and Technology conference.

Stephen L. Goldberg, Ph.D.
U.S. Army Research Institute for the Behavioral and Social Sciences (ARI)

Dr. Stephen L. Goldberg has over thirty-four years experience as a U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) Research Psychologist. Dr. Goldberg received a doctorate in Cognitive Psychology from the State University of New York at Buffalo in 1974. He has served as an ARI researcher at locations in Alexandria, VA, and Ft. Knox, KY. In 1984 he became ARI's liaison to the U.S. Army's Training and Doctrine Command (TRADOC), Ft. Monroe, VA. Dr. Goldberg assumed his current assignment as the Chief of ARI's Orlando (Advanced Training Technology) Research Unit in 1989. He supervises a research program focused on the behavioral aspects of training, with emphasis on feedback processes and training and performance in virtual simulations and games.

Dr. Goldberg served for five years as Chairman and U.S. National Leader for the Training Technology Panel of The Technical Cooperation Program (TTCP), an international program for data exchange and collaborative research between the United Kingdom, Canada, Australia, New Zealand, Australia, and the United States. Dr. Goldberg has also held leadership role in three NATO research study groups investigating the applicability of virtual environments to military operations and training. Dr. Goldberg is a past President and of the Society for Military Psychology (Division 19) of the American Psychological Association. He is a Fellow of the American Psychological Association and the American Educational Research Association.

Dr. Goldberg has authored numerous technical reports, book chapters, and conference presentations. His research interests include training methods, skill retention, use of virtual reality for training, and performance measurement.

<u>Frank L. Greitzer, Ph.D.</u>
<u>Pacific Northwest National Laboratory</u>

Frank L. Greitzer, Ph.D., is a Chief Scientist at the Pacific Northwest National Laboratory (PNNL), where he conducts R&D in human-information interaction for diverse problem domains. He holds a PhD degree in Mathematical Psychology with specialization in memory and cognition and a BS degree in Mathematics. Dr. Greitzer leads a R&D focus area of Cognitive Informatics that addresses human factors and social/behavioral science challenges through modeling and advanced engineering/computing approaches. With over thirty years of applied research and development experience in cognitive psychology, human information processing, and user-centered design, his research interests include modeling human behavior with application to identifying/predicting malicious insider cyber activities, modeling socio-cultural factors as predictors of terrorist activities, and human information interaction concepts for enhancing decision making in domains such as intelligence analysis or electric power grid operations. His research interests also include evaluation methods and metrics for assessing effectiveness of decision aids, analysis methods and displays. In the area of cyber security, Dr. Greitzer serves as Predictive Defense Focus Area Lead for the PNNL Information and Infrastructure Integrity Initiative. Dr. Greitzer also has conducted research to improve training effectiveness by applying cognitive principles in innovative, interactive, scenario-based training and serious gaming approaches. Many of his publications and descriptions of representative projects may be found at the Cognitive Informatics web site, http://www.pnl.gov/cogInformatics. In addition to his work at PNNL, Dr. Greitzer serves as an adjunct faculty member at Washington State University, Tri-Cities campus, where he teaches courses for the computer science department (interaction design) and for the psychology department (human factors). Dr. Greitzer also serves on the Editorial Board of the Journal of Cognitive Informatics & Natural Intelligence.

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Alice F. Healy
University of Colorado

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Education

Vassar College, Poughkeepsie, New York, A.B., 1968, Psychology
The Rockefeller University, New York, New York, Ph.D., 1973, Psychology

Positions and Employment

1968-1973 USPHS Training Grant Fellow, The Rockefeller University,
1968-1973 1973-1978 Assistant Professor of Psychology, Yale University
1978-1981 Associate Professor of Psychology, Yale University
1981-1984 Associate Professor of Psychology, University of Colorado, Boulder 1984-present
Professor of Psychology and Neuroscience, University of Colorado, Boulder 2007-present
College Professor of Distinction, University of Colorado, Boulder

Other Experience and Professional Memberships

1979-1981 Member, NIMH Basic Behavioral Processes Research Review Committee 1976-1980
Research Associate, Haskins Laboratories 1981-1984
Associate Editor, Journal of Experimental Psychology: Learning, Memory, and Cognition 1985-1989
Editor, Memory & Cognition 1987-1992
Member of the Governing Board, Psychonomic Society 1994-1995
President of Rocky Mountain Psychological Association 1995-1996
Chair of Electorate J (Psychology), American Association for the Advancement of Science 2004-2005
President of Division 3 (Experimental Psychology), American Psychological Association
2006-present Director, Center for Research on Training, University of Colorado, Boulder
2008-2009 Chair, Society of Experimental Psychologists

Honors

1987-1988 James McKeen Cattell Fund Sabbatical Award 2005 Women in Cognitive Science Mentorship Award 2006 Rocky Mountain Psychological Association Distinguished Service Award

Selected Publications

Schneider, V. I., Healy, A. F., & Bourne, L. E., Jr. (2002). What is learned under difficult conditions is hard to forget: Contextual interference effects in foreign vocabulary acquisition, retention, and transfer. Journal of Memory and Language, 46, 419-440.

Healy, A. F., Kole, J. A., Buck-Gengler, C. J., & Bourne, L. E., Jr. (2004). Effects of prolonged work on data entry speed and accuracy. Journal of Experimental Psychology: Applied, 10, 188-199.

Healy, A. F., Wohldmann, E. L., Parker, J. T., & Bourne, L. E., Jr. (2005). Skill training, retention, and transfer: The effects of a concurrent secondary task. Memory & Cognition, 33, 1457-1471.

Healy, A. F., Wohldmann, E. L., Sutton, E. M., & Bourne, L. E., Jr. (2006). Specificity effects in training and transfer of speeded responses. Journal of Experimental Psychology: Learning, Memory, and Cognition, 32, 534-546.

Kole, J. A., & Healy, A. F. (2007). Using prior knowledge to minimize interference when learning large amounts of information. Memory & Cognition, 35, 124-137.

Wohldmann, E. L., Healy, A. F., & Bourne, L. E., Jr. (2007). Pushing the limits of imagination: Mental practice for learning sequences. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33, 254-261.

Healy, A. F., Shea, K. M., Kole, J. A., & Cunningham, T. F. (2008). Position distinctiveness, item familiarity, and presentation frequency affect reconstruction of order in immediate episodic memory. Journal of Memory and Language, 58, 746-764.

Kole, J. A., Healy, A. F., & Bourne, L. E., Jr. (2008). Cognitive complications moderate the speed-accuracy tradeoff in data entry: A cognitive antidote to inhibition. Applied Cognitive Psychology, 22, 917-937.

Wohldmann, E. L., Healy, A. F., & Bourne, L. E., Jr. (2008). A mental practice superiority effect: Less retroactive interference and more transfer than physical practice. Journal of Experimental Psychology: Learning, Memory, and Cognition, 34, 823-833.

Wohldmann, E. L., Healy, A. F., & Bourne, L. E., Jr. (2008). Global inhibition and midcourse corrections in speeded aiming. Memory & Cognition, 36, 1228-1235.

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Lieutenant Colonel Gina Lee Hilger
U.S. Air Force

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Lieutenant Colonel Gina L. Hilger is the Chief of the Intelligence, Surveillance, and Reconnaissance (ISR) Requirements and Operations Division, Intelligence Directorate, US Air Forces Central, Shaw Air Force Base, South Carolina. She is responsible for providing collection management, multi-intelligence exploitation, and processing, exploitation, and dissemination support to combat operations in the US Central Command AOR.

Lieutenant Colonel Hilger was born in Belleville, IL on 12 September 1971 and received her commission in 1993 through the United States Air Force Academy.

Education
1993   Bachelor of Science degree in Political Science/Legal Studies and Spanish minor, US Air Force Academy
1995   Master's degree in International Security and Economic Policy, University of Maryland
1996   Intelligence Officer Training Course, Goodfellow AFB, TX
1998   Squadron Officer School, Maxwell AFB, AL
2001   Master's degree in Strategic Management, George Washington University
2003   Air Command and Staff College (Distance Learning)
2005   Master's degree in Counseling and Leadership, University of Colorado-Colorado Springs
2008   Air War College (Distance Learning)

Assignments
1. Aug 93-May 95, School of Public Affairs fellowship, University of Maryland, College Park, MD
2. Jun 95-Feb 96, Intelligence Officer Training Course, Goodfellow AFB, TX
3. Feb 96-Oct 96, Deputy Chief, 5th Air Force Bilateral Plans & Programs, Yokota AB, Japan
4. Oct 96-Jan 97, Liaison Officer & Command Briefer, ACOC, JTF-SWA, Riyadh, Saudi Arabia
5. Feb 97-Dec 97, Chief, Combat Ops Intel Division, 605 AIF, 5th Air Force, Yokota AB, Japan
6. Jan 98-Feb 98, Squadron Officer School, Maxwell AFB, AL
7. Mar 98-Jul 99, Chief, Operations Intel Element, 8th Operations Support Squadron, Kunsan AB, South Korea
8. Jul 99-Jun 01, Air Force Intern, Air Force Intern Program (AFIP), Pentagon, Washington, DC
9. Jun 01-Mar 03, Intel Flight Commander, 39th Operations Support Squadron, Incirlik AB, Turkey
10. Apr 03-May 04, Course Director, Intel Master Skills Course, 315th Training Squadron, Goodfellow AFB, TX
11. May 04-May 05, AFIT/IDE Student, University of Colorado-Colorado Springs, CO
12. May 05-Jul 07, Squadron Commander/Air Officer Commanding (AOC), Squadron Six, CG-01, USAFA, CO
13. Jul 07-Nov 07, Chief, Current Intel Branch, US Air Force Space Command, Peterson AFB, CO
14. Nov 07-Nov 08, Director of Operations, 732d Expeditionary Intel Squadron, Balad AB, Iraq

15. Feb 09-present, Chief, ISR Requirements and Operations Division, 9 AF/AFCENT, Shaw AFB, SC

Major Awards And Decorations
Outstanding Graduate, Air War College, Distance Learning, 2008
Meritorious Service Medal, oak leaf cluster
39th Operations Group CGO of the Year, 2002
7 AF / 8 FW Lance P. Sijan Award, 1999
5 AF Intel Officer of the Year, 1997
Joint Service Achievement Medal, oak leaf cluster
Air Force Commendation Medal, 2 x oak leaf clusters
Honor Graduate, Intel Officer Training Course, 1996
Co-Valedictorian, Master's in Public Management Program, Univ of MD, 1995
#1 Academic Graduate (1/963) and Distinguished Graduate (4/963), United States Air Force Academy, 1993

Effective Dates Of Promotion
Second Lieutenant   2 Jun 1993
First Lieutenant   2 Jun 1995
Captain   2 Jun 1997
Major   1 Aug 2003
Lieutenant Colonel 1 Aug 2008

<u>Robert R. Hoffman, Ph.D.</u>
<u>Institute for Human and Machine Cognition</u>

Hoffman is recognized as one of the world leaders in the field of cognitive systems engineering and Human-Centered Computing. He is a Fellow of the Association for Psychological Science and a Fulbright Scholar. His Ph.D. is in experimental psychology from the University of Cincinnati, where he received McMicken Scholar, Psi Chi, and Delta Tau Kappa Honors. Following a Postdoctoral Associateship at the Center for Research on Human Learning at the University of Minnesota, Hoffman joined the faculty of the Institute for Advanced Psychological Studies at Adelphi University. He began his career as a psycholinguist, and founded the journal, *Metaphor and Symbol*. His subsequent research leveraged the psycholinguistics background in the study of methods for eliciting the knowledge of domain experts. Hoffman has been recognized internationally in disciplines including psychology, remote sensing, weather forecasting, and artificial intelligence, for his research on human factors in remote sensing, his work in the psychology of expertise and the methodology of cognitive task analysis, and for his work on HCC issues intelligent systems technology and the design of macrocognitive work systems. Hoffman is a Co-Editor for the Department on Human-Centered Computing in *IEEE: Intelligent Systems*. He is Editor for the book Series, "Expertise: Research and Applications." He is a co-founder and Track Editor for the *Journal of Cognitive Engineering and Decision Making.* His major current projects involve evaluating the effectiveness of knowledge management, and performance measurement for macrocognitive work systems. A full vita and all of his publications are available for download at [www.ihmc.us/users/rhoffman/main].

Recent Books

Hoffman, R. R. and Militello, L. G. (2008). *Perspectives on Cognitive Task Analysis*: *Historical Origins and Modern Communities of Practice*. Boca Raton, FL: CRC Press/Taylor and Francis.

Crandall, B., Klein, G., & Hoffman, R. (2007). *Working minds: A practitioner's guide to cognitive task analysis.* Cambridge MA: MIT Press.

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

Selected Publications

Hoffman, R. R., Marx, M., Amin, R., & McDermott, P. (2010). Measurement for evaluating the learnability and resilience of methods of cognitive work. *Theoretical Issues in Ergonomic Science*, in press.

Hoffman, R. R., Lee, J. D., Woods, D. D., Shadbolt, N., Miller, J. & Bradshaw, J. M. (2009, November/December). The dynamics of trust in cyberdomains. *IEEE Intelligent Systems*, pp. 5-11.

Hoffman, R. R., Fiore, S. M., Klein, G., Feltovich, P. and Ziebell, D. (2009, March/April). Accelerated learning (?). *IEEE: Intelligent Systems*, pp. 18-22.

Hoffman, R. R., Neville, K. N. and Fowlkes, J. (2009). Using cognitive task analysis to explore issues in the procurement of intelligent decision support systems. *Cognition, Technology, and Work, 11,* 57-70.

Hoffman, R. R. (2008). Human factors contributions to knowledge elicitation. *Human Factors* (Special 50th Anniversary Issue), *50*, 481-488.

Hoffman, R. R., Ziebell, D., Fiore, S. M. and Becerra-Fernandez, I. (2008, May/June). Knowledge management revisited. *IEEE: Intelligent Systems*, pp. 84-88.

Klein, G., Moon, B., & Hoffman, R. R. (2006, July/August). Making sense of sensemaking. *IEEE Intelligent Systems*, pp. 22-26.

Hoffman, R. R., & Shattuck, L. G. (2006/March-April). Should we rethink how we do OPORDs? *Military Review*, pp. 100-107.

Hoffman, R. R., Coffey, J. W., Ford, K. M., & Novak, J. D. (2006). A method for eliciting, preserving, and sharing the knowledge of forecasters. *Weather and Forecasting, 21*, 416–428.

Hoffman, R. R., & Woods, D. D. (January/February, 2005). Steps toward a theory of complex and cognitive systems. *IEEE: Intelligent Systems*, pp. 76-79.

Hoffman, R. R., & Deffenbacher, K. A. (1993). An analysis of the relations of basic and applied science. *Ecological Psychology, 5*, 315-352.

Robert C. Hubal
RTI International Research, Inc.

Robert Hubal, senior research psychologist in RTI's Substance Abuse Epidemiology and Military Behavioral Health Program, conducts wide-ranging research generally focusing on the intelligent use of advanced technologies for training, work performance, and assessment. Dr. Hubal has research experience developing embodied conversational agents for interaction skills training and situated assessment, conducting cost-effectiveness studies of virtual reality systems, conducting expertise and linguistic codability studies, investigating adaptive intelligent tutoring, studying driver training and assessment, and investigating visual analytics and representation. He has applied research results to such everyday domains as medical informed consent, consumer decision making, driving, and survey nonresponse training.

PhD, Cognitive Psychology, Duke University, 1996.
MS, Computer Science, North Carolina State University, 1992.
SB, Computer Science and Engineering, Massachusetts Institute of Technology, 1987.

Professional Experience
1996 to date   RTI International, Research Triangle Park, NC.
1992 to 1996, 2000   Duke University, Durham, NC.

Selected Book Chapters

Eriksson, E.J., Rodman, R.D., & Hubal, R.C. (2007). Emotions in speech: Juristic implications. In C. Muller (Ed.), *Speaker classification I: Fundamentals, features, and methods* (pp. 152-173). Heidelberg, Germany: Springer-Verlag.

Hubal, R., Kizakevich, P., & Furberg, R. (2007). Synthetic characters in health-related applications. In S. Vaidya, L.C. Jain, & H. Yoshida (Eds.), *Advanced computational intelligence paradigms in healthcare 2* (pp. 5-26). Heidelberg, Germany: Springer-Verlag.

Kizakevich, P.N., Culwell, A., Furberg, R., Gemeinhardt, D., Grantlin, S., Hubal, R., Stafford, A., & Dombroski, R.T. (2007). Virtual simulation-enhanced triage training for Iraqi medical personnel. In J.D. Westwood, R.S. Haluck, H.M. Hoffman, G.T. Mogel, R. Phillips, R.A. Robb, & K.G. Vosburgh (Eds.), *In vivo, in vitro, in silico: Designing the next in medicine* (pp. 223-228). Amsterdam: IOS Press.

Armsby, P.P., Link, M.W., Hubal, R., Guinn, C.I., Flicker, L., & Caspar, R. (2003). Accessibility and acceptance of a virtual respondent-based interviewer training application. In R. Banks et al. (Eds.), *Survey and statistical computing IV: The impact of technology on the survey process*. Chesham, Bucks, UK: Association for Survey Computing.

Hubal, R.C., Kizakevich, P., Guinn, C.I., Merino, K.D., & West, S.L. (2000). The virtual standardized patient: Simulated patient-practitioner dialogue for patient interview training. In J.D. Westwood, H.M. Hoffman, G.T. Mogel, R.A. Robb, & D. Stredney (Eds.), *Envisioning healing: Interactive technology and the patient-practitioner dialogue* (pp. 133-138). Amsterdam: IOS Press.

Selected Peer-Reviewed Journal Articles

Fishbein, H.A., Sheppard, M.E., Hyde, C., Hubal, R.C., Newlin, D.B., Serin, R., Chrousos, G., & Alesci, S. (in press). Neurocognitive and emotional regulatory deficits predict treatment response in prison inmates. Behavior and the Law.

Hubal, R. (2008). Embodied tutors for interaction skills simulation training. International Journal of Virtual Reality, 7(1), 1-8.

Hubal, R.C., Evens, N.R, FitzGerald, D.P., Hardy, K.K., Willard, V.W., & Bonner, M.J. (2008). Implementation of FACS Training Systems Association.

Frank, G.A., & Hubal, R.C. (2008). Bias inoculation advanced simulation (BIAS) training. Proceedings of the Behavior Representation in Modeling and Simulation conference. Orlando, FL: Simulation Interoperability Standards Organization.

Hubal, R., & Frank, G. (2008). Enticing mistakes: A strategy within simulation training of soft skills. Proceedings of the Interservice/Industry Training, Simulation and Education Conference (pp. 57-66). Arlington, VA: National Training Systems Association.

Krizowsky, P., Waters, H., Wright, M., Hubal, R., & Frank, G. (2008). Dynamically configured scenarios for training adaptive network system operators. Proceedings of the

Interservice/Industry Training, Simulation and Education Conference (pp. 1392-1399). Arlington, VA: National Training Systems Association.

Frank, G., Hubal, R., & O'Bea, M. (2007). Using competency definitions to adapt training for mission success. Proceedings of the Interservice/Industry Training, Simulation and Education Conference (pp. 1262-1270). Arlington, VA: National Defense Industrial Association.for synthetic characters for use in studying facial expression recognition by survivors of childhood cancer. Annual Review of CyberTherapy and Telemedicine, 6, 35-40.

Hubal, R.C., Fishbein, D.H., Sheppard, M.S., Eldreth, D.L., & Hyde, C.T. (2008). How do varied populations interact with embodied conversational agents? Findings from inner-city adolescents and prisoners. Computers in Human Behavior, 24(3), 1104-1138.

Paschall, M.J., Fishbein, D.H., Hubal, R.C., & Eldreth, D. (2005). Psychometric properties of virtual reality vignette performance measures: A novel approach for assessing adolescents' social competency skills. Health Education Research: Theory and Practice, 20(1), 61-70.

Hubal, R.C., Deterding, R.R., Frank, G.A., Schwetzke, H.F., & Kizakevich, P. (2003). Lessons learned in modeling virtual pediatric patients. Studies in Health Technology and Informatics, 94, 127-130.

Selected Presentations, Reports, and Proceedings

Hedge, J., & Hubal, R. (2009). Job proficiency work sample testing for critical DHS jobs and job tasks. Research Brief Pre-Project Report prepared for the Institute for Homeland Security Solutions, Research Triangle Park, NC.

Hubal, R.C. (2009). Mental models for effective training: Comparing expert and novice maintainers' mental models. Research Report 1898. Arlington, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Frank, G., Evens, N., Hubal, R., & Whiteford, B. (2008). Automated, interactive AARs: A positive spin. Proceedings of the Interservice/Industry Training, Simulation and Education Conference (pp. 67-76). Arlington, VA: National

Frank, G., Whiteford, B., Hubal, R., Sonker, P., Perkins, K., Arnold, P., Presley, T., Jones, R., & Meeds, H. (2004). Performance assessment for distributed learning using after action review reports generated by simulations. Proceedings of the Interservice/Industry Training, Simulation and Education Conference (pp. 808-817). Arlington, VA: National Training Systems Association.

Guinn, C., & Hubal, R. (2003). Extracting emotional information from the text of spoken dialog. Proceedings of the Workshop on Assessing and Adapting to User Attitudes and Affect: Why, When and How? Johnstown, PA: User Modeling, Inc.

Maggart, L.E., & Hubal, R.C. (1998). A situation awareness model. In S.E. Graham & M.D. Matthews (Eds.), Infantry situation awareness: Papers from the 1998 Infantry Situation Awareness Workshop (pp. 19-28). Alexandria, VA: U.S. Army Research Institute.

Gary Klein
Macrocognition LLC and Klein Associates Division of ARA, Inc.

Gary Klein, Ph.D. is a Senior Scientist at MacroCognition LLC, and also at Applied Research Associates. He splits his time between the two companies, working 52% at MarcoCognition LLC, and 48% at ARA. He was instrumental in founding the field of Naturalistic Decision Making.

Dr. Klein received his Ph.D. in experimental psychology from the University of Pittsburgh in 1969. He was an Assistant Professor of Psychology at Oakland University (1970-1974) and worked as a research psychologist for the U.S. Air Force (1974-1978). The R&D company he founded in 1978, Klein Associates, was acquired by ARA in 2005.

He has written: *Sources of Power: How People Make Decisions* (1998); *The Power of Intuition* (2004) and *Working Minds: A practitioner's guide to Cognitive Task Analysis* (Crandall, Klein, & Hoffman, 2006). Dr. Klein's next book, *Streetlights and Shadows: Searching for the keys to adaptive decision making,* is due out in November 2009.

Dr. Klein developed a Recognition-Primed Decision (RPD) model to describe how people actually make decisions in natural settings. He also developed methods of Cognitive Task Analysis for uncovering the tacit knowledge that goes into decision making. He was selected as a Fellow of Division 19 of the American Psychological Association in 2006, and in 2008 he received the Jack A. Kraft Innovator Award from the Human Factors and Ergonomics Society.

Lochlan E. Magee
Defence Research and Development Canada

Dr. Magee graduated from the University of Toronto with a PhD in 1982 in experimental psychology, with specialization in human information processing. He received National Research Council of Canada and Ontario Graduate Student scholarships during his studies.

In 1980 he joined Defence Research and Development Canada as a Defence Scientist (DS) and became responsible for the conduct and management of R&D activities associated with the design, use and evaluation of simulators for the CF.

His major career accomplishments include the generation and application of human factors knowledge in the design and assessment of low-cost simulators. These include invention of training simulators for the land (Leopard C1 tank gunnery trainer & TOW guided missile simulator), maritime (submarine periscope simulator & officer-of-the-watch simulator) and air (Sea King helicopter) environments. Dr Magee has also patented enabling technology (i.e., an interactive video processor), investigated unwanted side effects of simulator use, and licensed software and know-how to industry.

He is currently working on new approaches for training helicopter flight deck operations and investigating technologies for embedded training systems within operational equipment. In 2007, the Air Force Association of Canada recognized the efforts that he led on helicopter simulation as an outstanding contribution to military aviation in Canada.

Harry O'Neil

Harry O'Neil's interest in technology and education and training began at Florida State University. In 1975, he was recruited to join the Defense Advanced Research Projects Agency (DARPA). From 1978 to 1985 he served in various research roles at the Army Research Institute for Behavioral and Social Sciences (ARI). He was a member of the Senior Executive Service. In the mid 1980s, O'Neil assumed a position as Full Professor of Educational Psychology and Technology at USC. He has been a member of the Army Science Board and various Defense Science Board Task Forces. He is a Fellow of the American Psychological Association and a Certified Performance Technologist. A prolific writer, he has recently co-edited four books— *What Works in Distance Learning: Guidelines* (2005), *Web-Based Learning: Theory, Research, and Practice* (2006), *Assessment of Problem Solving Using Simulations* (2008), and *Computer Games and Team and Adult Learning* (2008).

Robert Patterson
Washington State University

Professor   Research Scientist Consultant
Deparment of Psychology   Link Simulation and Training
and Program in Neuroscience   L-3 Communications
Washington State University   Air Force Research Laboratory
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Areas Of Expertise
Cognitive Science, Visual Perception & Applied Vision, Experimental Design, System Dynamics Modeling

Education
1976 B.A. Behavioral Science, San Jose State University
1978 M.A. Experimental Psychology, San Jose State University
1984 Ph.D. Experimental Psychology, Vanderbilt University
1985-7 Postdoctoral Research Fellow, Visual Neuroscience, Northwestern University

Selected Publications

Patterson, R., Geri, G.A., Dyre, B.P., Akhtar, S.C., Covas, C.M., & Pierce, B.J. (2005). Altitude control in simulated flight using 3D objects and terrain texture. *Journal of the Society for Information Display*, *13*, 1039-1044.

Patterson, R., Geri, G.A., Dyre, B.P., Pierce, B.J., Akhtar, S.C., Covas, C.M.& Morgan, W. (2006). Active heading control in simulated flight based on vertically extended contours. *Perception & Psychophysics, 68*, 593-600.

Patterson, R., Winterbottom, M. & Pierce, B.J. (2006). Perceptual Issues with the use of head-mounted displays (review paper). *Human Factors, 48*, 555-573.

Winterbottom, M.D., Patterson, R., Pierce, B.J., Covas, C. & Winner, J. (2007). Depth of focus and visual recognition of imagery presented on simultaneously viewed displays: Implications for head-mounted displays. *Human Factors, 49*, 907-919.

Patterson, R., Winterbottom, M., Pierce, B.J. & Fox, R. (2007). Binocular rivalry and head-mounted displays (review paper). *Human Factors, 49*, 1083-1096.

Patterson, R. (2007). Human factors of 3D displays (review paper). *Journal of the Society for Information Display*, 15, 861-871.

Patterson, R. & Silzars, A. (2009). Immersive stereo displays, intuitive reasoning, and cognitive engineering. *Journal of the Society for Information Display*, *17*, 443-448.

Patterson, R., Fournier, L., Pierce, B.P., Winterbottom, M. & Tripp, L. (2009). System dynamics modeling of the recognition-primed decision model. *Journal of Cognitive Engineering and Decision Making*, in press.

Patterson, R., Pierce, B.P., Bell, H., Andrews, D. & Winterbottom, M. (2009). Training robust decision making in immersive environments (review paper). *Journal of Cognitive Engineering and Decision Making*, in press.

Robert W. Proctor
Purdue University

Distinguished Professor of Psychological Sciences
Purdue University
703 Third S.,
West Lafayette, IN 47907-2081
Phone: (765) 494-0784,
FAX: (765) 496-1264,
Email: proctor@psych.purdue.edu

Education
    University of Texas, Austin,   Major: Psychology, B.A., 1970
    University of Texas, Arlington, Major: Experimental Psychology, M.A., 1972; Ph.D., 1975

Appointments
    Department of Psychological Sciences, Purdue University: Distinguished Professor (2008-present).
    Department of Psychological Sciences, Purdue University: Professor (1988 – 2007).
    Department of Psychology, Auburn University: Associate Professor (1980 – 1988).
    Department of Psychology, Auburn University: Assistant Professor (1976 – 1980).
    Department of Psychology, Michigan State University: Assistant Professor (1975 – 1976)

Selected Publications

Yamaguchi, M., & Proctor, R. W. (2009). Transfer of learning in choice reactions: Contributions of specific and general components of manual responses. Acta Psychologica, 130, 1–10.

Bae, G. Y., Cho, Y. S., & Proctor, R. W. (2009). Transfer of orthogonal stimulus-response mappings to an orthogonal Simon task. *Quarterly Journal of Experimental Psychology, 62*, 746-765.

Proctor, R. W., Yamaguchi, M., Zhang, Y., & Vu, K.-P. L. (2009). Influence of visual stimulus mode on transfer of acquired spatial associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 434-445.

Proctor, R. W., & Van Zandt, T. (2008). *Human factors in simple and complex systems* (2nd ed.). Boca Raton, FL: CRC Press.

Proctor, R. W., Yamaguchi, M., & Vu, K.-P. L. (2007). Transfer of noncorresponding spatial associations to the auditory Simon task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 245-253.

Wang, D.-Y. D., Proctor, R. W., & Pick, D. F. (2007). Acquisition and transfer of attention-allocation strategies in a multiple-task work environment. *Human Factors, 49*, 995-1004.

Proctor, R. W., Vu, K.-P. L., & Pick, D. F. (2005). Aging and response selection in spatial choice tasks. *Human Factors, 47*, 250-270.

Proctor, R. W., & Vu, K.-P. L. (2006). *Stimulus-response compatibility principles: Data, theory, and application*. Boca Raton, FL: CRC Press.

Proctor, R. W., & Vu, K.-P. L. (2006). Laboratory studies of training, skill acquisition, and retention of performance. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *Cambridge handbook of expertise and expert performance* (pp. 265-286). Cambridge, UK: Cambridge University Press.

Proctor, R. W., Tan, H. Z., Vu, K.-P. L., Gray, R., & Spence, C. (2005). Implications of compatibility and cuing effects for multimodal interfaces. In D. D. Schmorrow (Ed.), *Foundations of augmented cognition* (pp. 3-12). Mahwah, NJ: Lawrence Erlbaum Associates.

Proctor, R. W., & Dutta, A. (1995). *Skill acquisition and human performance*. Thousand Oaks, CA: Sage.

Editorial Positions

Editor: *American Journal of Psychology*, March 1, 2008 to present; Editor: *Behavior Research Methods, Instruments, & Computers*, 1994-1999; Associate Editor: *Memory & Cognition*, 1986-1993; *International Journal of Human-Computer Interaction*, 1992-2000; *Quarterly Journal of Experimental Psychology*, 2001-2005; Consulting Editor: *Perception & Psychophysics*, 1983-1998; *International Journal of Human-Computer Interaction*, 2001-present; *Journal of Experimental Psychology: Human Perception and Performance*, 2001-present; *Acta Psychologica*, 2006-present; *Human Factors*, 2006-present; *Psychological Research/Psychologische Forschung*, 2009-present; *Memory & Cognition*, 2009- present.

Rand J. Spiro
Michigan State University

Rand J. Spiro, Ph.D., is a professor of Educational Psychology and Educational Technology at Michigan State University and a principal investigator in the Literacy Achievement Research Center (LARC). Before coming to MSU, Dr. Spiro was a Distinguished Senior Scholar in the College of Education at the University of Illinois at Urbana-Champaign, where he was Professor of Educational Psychology, Psychology, and the Beckman Institute for Advanced Science and Technology. He has been a Visiting Scientist in Psychology and Computer Science at Yale University, where he worked in the Yale Artificial Intelligence Laboratory, and a Visiting Professor of Education at Harvard University. He was a founding member and served for a time as co-director of the national Center for the Study of Reading at the University of Illinois. He also served as Chair of the Department of Educational Psychology at Illinois.

Spiro has been quoted and his ideas discussed in such national media outlets as, most recently, the New York Times, the Washington Post, and the Wall Street Journal. Altogether, Spiro has made over 100 invited presentations to scholarly groups, including major invited addresses to professional societies such as the American Psychological Association (co-

sponsored by the Experimental Psychology and Educational Psychology divisions), the Cognitive Science Society, the American Educational Research Association (three invited addresses: one for Division C, one for Division I and one for Division K). the International Reading Association, the National Conference on Research in English (President's Invitational Address), the Semiotics Society of America, the National Reading Conference (two major invited addresses), a Director's Invitational Seminar at the Beckman Institute for Advanced Science and Technology, invited panelist at the Franklin Institute Awards (panel for Donald Norman, laureate in computer and cognitive science), invited colloquia at universities such as Harvard, Yale, Michigan, Northwestern, New York University, Georgia, Indiana, Washington, Arizona, Delaware, Georgia Tech, Wisconsin, McGill, Lisbon, Rome, Tokyo, Canterbury (New Zealand), universities in Beijing and Shanghai, and various universities in Portugal (under the sponsorship of the Joint Luso-American Fulbright Commission), invited talks at NATO conferences in Brussels (Belgium), Leuven (Belgium), Espinho (Portugal), Crete (Greece), Aix-en-Provence (France), and Edinburgh (UK), and numerous other invited presentations around the world.

He has been a principal or co-principal investigator on grants from the National Science Foundation, the US Department of Education, the US Department of Health and Human Services, the Spencer Foundation, the Joyce Foundation, IBM, Apple, the Department of Defense, among others.

Dr. Spiro is the co-originator of Cognitive Flexibility Theory and its application to innovative approaches to hypermedia design. His research areas include new forms of reading and learning on the Web, knowledge acquisition in complex domains, hypermedia learning environments, multimedia case-based methods in professional education, experience acceleration, biomedical cognition, learning in history, and constructive processes in comprehension and recall. Much of his research is concerned with determining how learning should proceed so that tendencies toward conceptual oversimplification are counteracted and a wide range of future applications of knowledge are supported. A central focus is the development and testing of theory-based hypermedia learning environments designed to promote cognitive flexibility. His publications include the books Schooling and the Acquisition of Knowledge; Theoretical Issues in Reading Comprehension; Cognition, Education, and Multimedia; and Hypertext & Cognition, as well as numerous articles in scholarly journals and chapters in edited volumes.

Kurt VanLehn is a Professor in the School of Computing and Informatics at Arizona State University. He received a Ph. D. from MIT in 1983 in Computer Science, was a post-doc at BBN and Xerox PARC, joined the faculty of Carnegie-Mellon University in 1985, moved to the University of Pittsburgh in 1990 and joined ASU in 2008. He founded and co-directed two large NSF research centers (Circle; the Pittsburgh Science of Learning Center). He has published over 125 peer-reviewed publications, is a fellow in the Cognitive Science Society, and is on the editorial boards of *Cognition and Instruction*, and the *International Journal of Artificial Intelligence in Education*.

Dr. VanLehn's research focuses on applications of artificial intelligence to education and cognitive modeling. Some of his recent projects are: *Andes*, an intelligent tutoring system for a full year of college/high school physics that improves students grades by approximate a letter grade and is in daily use around the country; *Why2-Atlas* and *Cordillera*, two intelligent tutoring systems that pioneered the use of natural language dialogues for science teaching and have been shown to be just as effective as expert human tutors; *Pyrenees*, an intelligent tutoring system that successfully caused inter-domain transfer by implicitly teaching a meta-cognitive strategy; and *Cascade*, a highly accurate cognitive model of human students learning physics that accounts for the interaction of self-explanation and analogy.

Karen Velkey
Northrop Grumman Corporation

Education

Millsaps College, Jackson, MS	BA	1987-1991	Psychology
The University of Montana, Missoula, MT	MBA	1992-1994	Business

Employment History

Compensation Manager, Northrop Grumman Corporation, 2008-Present
Compensation Analyst, Northrop Grumman Corporation, 2001-2008
HR Associate, Payroll Coordinator, Purchasing Agent, Double G Coatings, Byrum, Mississippi, 1998-2001
Visiting Instructor, University of Montana, School of Business Administration, Missoula, MT 1995-1997
Compensation & Benefits, Sr. Patrick Hospital, Missoula, MT 1994-1996

Karen has over ten years experience in Human Resources, with an emphasis in Compensation. Her work in compensation includes job analysis and evaluation, salary structure design and implementation, and bonus administration. She recently led a 2 year project for Northrop Grumman to standardize job coding, titling, and baseline market data across the corporation. She continues to work with functional groups across the organization to align job families and titles with competency models and organizational development goals. Karen also serves on the High Technology Advisory Committee for the SIRS (Salary Information Retrieval System) survey group of Organization Resource Consultants. Karen taught Organizational Behavior and

Personal Selling at the University of Montana, and has developed and provided training in all aspects of HR including job evaluation, market data analysis, compliance, safety, and customer service.

Colonel Daniel R. Walker
Air Force Research Laboratory

Colonel Daniel R. Walker is the Chief, Warfighter Readiness Research Division, and Commander, Mesa Research Site, Air Force Research Laboratory, Mesa, Arizona. He directs research and development (R&D) for Air Force Material Command's premier training research organization, developing advanced systems, tools, & methods to improve warfighter performance. Col Walker manages over $50M annually to facilitate programs ensuring optimum solutions to real world training requirements, integrating efforts between warfighters, force providers, combatant commands, industry, academia, and acquisition agencies. The division employs over 250 uniformed military, government civilian and contractor scientists, engineers and technicians. He directs all civil engineering, security, morale and welfare, and professional development activities for the site.

Col Walker holds four Master's degrees and is pursuing a PhD in Training and Performance Improvement. He has extensive experience in aircrew training and joint operations including command of the B-1 Division, USAF Weapons School, and duty as Assistant Deputy Director of Operations for JTF SWA, where he participated in the planning and execution of Operation Desert Fox, the first combat employment of the B-1.

Education
2002 M.A., National Security and Strategic Studies, Naval War College, Newport, Rhode Island
2000 Air War College
1996 Joint and Combined Staff Officer School, Armed Forces Staff College, Norfolk, VA
1995 M.A.A.S, Airpower Arts and Science, School of Advanced Airpower Studies, Maxwell AFB, AL
1994 M.M.A.S, Military Arts and Science, US Army Command and General Staff College, Ft Leavenworth, KS
1992 USAF Weapons School, Nellis AFB, NV and Ellsworth AFB, SD
1985 M.A., Management and Supervision, Central Michigan University
1985 Marine Corps Command and Staff College
1985 Squadron Officers School, Maxwell AFB AL
1980 B.S., Biology, United States Air Force Academy

Assignments
May 05–Present   Chief, Warfighter Readiness Research Division and
                  Commander, Mesa Research Site, Air Force Research Laboratory, Mesa, AZ
Jun 04–May 05   Chief, Nuclear Policy Division, The Joint Staff, J-5, Washington, D.C.
Jun 02–Jun 04   Chief, Strategic Nuclear Policy, The Joint Staff, J-5, Washington, D.C.
Jun 01–Jun 02   Naval War College, Newport, RI
Jun 99–Jun 01   Commander, USAF Weapons School B-1 Division and Detachment 4, 57th Wing,
                  Ellsworth AFB, SD.
Jul 98–May 99   Assistant Operations Officer, 37th Bomb Squadron, Ellsworth AFB, SD

Jul 95–Jun 98	Chief, Air Operations, US Atlantic Command, J-3, Norfolk, VA
Jun 94–Jun 95	School of Advanced Airpower Studies, Maxwell AFB, AL
Jun 93–Jun 94	US Army Command and General Staff College, Ft Leavenworth, KS
Aug 92–Jun 93	Operations Officer, B-1 Division, USAF Weapons School, Ellsworth AFB, SD
Feb 92–Aug 92	Chief, Flight Operations, Bomber/Tanker Employment School, Ellsworth AFB, SD
Jun 91–Feb 92	Executive Officer, Strategic Warfare Center, Ellsworth AFB, SD
Mar 91–Jun 91	B-1 Tactics Program Manager, 99th Strategic Weapons Wing, Ellsworth AFB, SD
Nov 89–Mar 91	Chief of Offensive Systems, 25th Strategic Training Squadron, Ellsworth AFB, SD
Nov 88–Nov 89	Chief, Target Study Section, 28th Bomb Wing, Ellsworth AFB, SD
Aug 87–Nov 88	B-1 Instructor Offensive Systems Officer, 37th Bomb Sq, Ellsworth AFB, SD
Oct 86–Aug 87	B-1 Combat Crew Training, 338th Strategic Training Sq, Dyess AFB, TX
Jun 85–Oct 86	Target Study Officer, 319th Bomb Wing Grand Forks AFB, ND
Jun 82–Jun 85	B-52G/H Evaluator Navigator, Instructor Radar Navigator, 46th Bomb Sq, Grand Forks AFB, ND
Jul 80–Jun 82	Undergraduate, Advanced Flying, and B-52 Combat Crew Training

Flight Information
Rating:	Master Navigator
Flight Hours:	More than 2,500
Aircraft Flown:	B-1, B-52

Awards
Defense Superior Service Medal
Joint Meritorious Service Medal
Meritorious Service Medal with two oak leaf clusters
Air Force Commendation Medal
Joint Service Achievement Medal with oak leaf cluster
Air Force Achievement Medal with oak leaf cluster
Combat Readiness Medal with oak leaf cluster
National Defense Service Medal with gold star
Armed Forces Expeditionary Medal
War on Terror Service Medal

Other Achievements
1989 Fairchild Trophy for Most Outstanding Bombing and Navigation in Strategic Air Command

Professional Certifications
Defense Acquisition Workforce Improvement Act: Systems Planning, Research, Development and Engineering, Level III
Program Management, Level I

Selected Publications
Walker, D. R., & Geiss, K. T. (In Press). Future Air Force Training. In D. Schmorrow, J. Cohn & D. Nicholson (Eds.), *The PSI Handbook of Virtual Environments for Training and Education: Developments for the Military and Beyond*. Westport, CT: Praeger Security International.

Walker, D. R. (1996). *The Organization and Training of Joint Task Forces*. Maxwell AFB, AL: Air University Press.

Professional Associations
Air Force Association
Armed Forces Chapter- International Society for Performance Improvement
American Society for Training and Development
Association of Old Crows - The Electronic Warfare and Information Operations Association
Kappa Delta Pi - Honor Society for Education
National Air and Space Society
National Training and Simulation Association

Effective Dates Of Promotion
Colonel   01 Nov 2002
Lieutenant Colonel   01 July 1997
Major   01 June 1992
Captain   28 May 1984
First Lieutenant   28 May 1982
Second Lieutenant   28 May 1980
 (Current as of Sep 2008)

David M. Ziebell
Electric Power Research Institute

David Ziebell is a Senior Project Manager in the Equipment Reliability program area of the Nuclear Sector. His recent research activities focus on Expert Knowledge Capture and Transfer, one of several industry responses to knowledge loss due the aging workforce. Ongoing research and development activities support nuclear generating plant operations and maintenance with organizational performance and process improvement, and procedure and work practice effectiveness.

Mr. Ziebell joined EPRI in 2003 as the Manager, Human Performance Technology. His activities focused on development of leading indicators of human performance, supporting performance improvement process benchmarking with the Nuclear Energy Institute, and developing cross-functional aspects of human performance for all sectors in the electric industry.

Before joining EPRI, Mr. Ziebell worked at the Institute of Nuclear Power Operations, and was involved in various activities providing evaluation and assistance services to nuclear utilities in both operations and human performance. He also worked at Southern California Edison as senior reactor operator and shift manager, and served as a submarine qualified officer in the U.S. Navy.

Mr. Ziebell received a BS degree in Atmospheric Science from Purdue University.

PRE-MEETING POSITION PAPERS

Neil Charness, Ph.D., Florida State University
Jared Freeman, Ph.D., Aptima, Inc.
Andy Gibbons, Ph.D., Brigham Young University
Frank L. Greitzer, Ph.D., Pacific Northwest National Laboratory
Alice F. Healy, Ph.D., University of Colorado
Robert Hubal, RTI International
Harry O'Neil, Ph.D.. University of Southern California
Robert Patterson, Ph.D., Washington State University
Robert Proctor, Ph.D.. Purdue University
Karen Velkey, Northrop-Grumman
David Ziebell, Electric Power Research Institute

Neil Charness, Ph.D.
Florida State University

I'm going to adopt the strengths, weaknesses, opportunities, and threats (SWOT) framework for musing about some of the topisc.

Accelerated Learning Topic
Strengths: We are beginning to understand what are effective schedules for training for retention (e.g., for foreign language – Pavlik & Anderson). We have very sophisticated tools for analyzing developmental studies (e.g., longitudinal data sets) such as multi-level modeling techniques, trajectory analysis techniques.

Weaknesses: Most lab studies of learning involve declarative memory skills (word list and paired associate tasks) rather than procedural skills and the latter may be more relevant for military tasks such as piloting, marksmanship, mine detection, which involve a mix of both types of learning.

Opportunities: Developing and comparing different training techniques (hands-on, simulation environments of varying fidelity) and doing longitudinal studies within a diverse population of learners.

Threats: Not having validated measurement tools for proficiency assessment for many real-world tasks, generalizing to diverse populations of trainees (diversity of educational backgrounds, ages, and proficiency levels after initial training). Ability to mount long enough longitudinal studies to model typical interrupted careers.

Retention of Skill Topic
Strengths: We know a great deal about memory for information post learning, ranging from minutes (lab science) to years (Open University psychology course material) to decades (language skills – Bahrick).

Weaknesses: We do not have much information about individual difference predictors of skill retention, such as age, gender, cognitive ability level, education level, etc. We lack information about how booster sessions (number, spacing) affect learning and forgetting rates. Do not have solid data about job requirement changes and transfer of skills within careers (e.g., piloting a jet versus a UAV; Air Traffic Control with changing technology) and knowledge obsolescence in jobs and what motivates people to engage in the type of deliberate practice needed to maintain and develop skill.

Opportunities: Tracking job requirements longitudinally in a rapidly changing job environment (e.g., technology adoption issues); understanding career trajectories in the military and how that affects recruitment and retention, particularly within an aging civilian population; developing measures of motivation that might predict attrition.

Threats: Same as above for accelerated learning.

Jared Freeman, Ph.D.
Aptima, Inc.

The Accelerated Learning workshop will address a variety of fundamental issues in the learning sciences (e.g., measurement, scaffolding, resilience).

We posit that instructional technology should be considered early in these discussions, both because the planned topics may inform the definition of requirements for such technology, and because appropriate technology potentially enhances our ability to address the workshop issues over the long term.

Several classes of technology may be central to implementing Accelerated Learning concepts:

• Pervasive technology for human performance measurement is needed to estimate the effects of training, in the short term, and to validate and calibrate the impact of competencies on task performance, in the long term.

• Scenario engineering technology is required to dynamically adapt training simulations and games in ways that ensure students are continuously stimulated by events that exercise and extend their competencies. In the long term, such technology should help us to assess whether training in specific competencies is feasible in simulations.

• Formal (computational) representations of competency and its impact on operational tasks (e.g., accelerating performance, raising quality) are needed to model and support the performance of military organizations under different assumptions about staff composition and size.

Andy Gibbons, Ph.D.
Brigham Young University

The team aspect of performance is one of the most critical issues. Therefore, consideration must be given to:

a. Helping team members become metacognitive about their participation in a team.

b. Allowing practice with feedback to occur at the team level as frequently as required for expertise-building in that set of skills. This will require a socially-networked venue among widely-distributed personnel.

c. Giving team members a clear idea of the "personas"—the multiple contributory functions—that make up a full-function team. In this respect, there are useful clues in The Ten Faces of Innovation, by Kelley. The book is written with design teams in mind; the priority on training and performance teams that can innovate and solve problems fits nicely with this theme.

Several workshop issues such as deep structure, fine discriminations, transfer, progressive development, and the learning of tacit knowledge that is useful in real situations can be helped by a re-visitation of the "increasingly complex microworlds" theme as expressed by Burton, Brown, and Fischer (Burton, R. R., Brown, J. S., & Fischer, G. (1984): "Skiing as a Model of Instruction" — In B. Rogoff, & J. Lave (Eds.), Everyday Cognition: Its Development in Social Context, Harvard. Access at: http://l3d.cs.colorado.edu/~gerhard/papers/skiing-paper-1984.pdf). There is a precision attainable in training effect through careful selection and sequencing of training problems. There are efficiency, contrast, and repetition effects possible when staccato problem sequences are used which change only one or a few problem variables of interest. University Press, Cambridge, MA and London, pp. 139-150.). When ICM was originally expressed by them (and later by others), it was done qualitatively. Perhaps the time has come to give a more quantitative treatment to this concept which would allow the scaling of problems and more nuanced sequencing schemes. Work by Victor Bunderson on "domain theory" is relevant here. (See Bunderson, C.V. (2006). Developing a domain theory: Defining and exemplifying a learning theory of progressive attainments. In M. Garner, G. Engelhard, M. Wilson, & W. Fisher (Eds.), Advances in Rasch measurement, Volume I. Maple Grove, MN: JAM Press.)

It seems relevant to bring up the design-based research approach in connection with this ambitious research agenda. DBR is appropriate for exactly the messy and complex problems this workshop is dealing with. In principle, it would allow a more flexible approach to both problem-finding and solution framing, and it pre-supposes inter-silo, team-based, and exploratory research processes.

It may be appropriate to consider the area of weather forecasting and analysis as one of the subject-matter areas to research. Several factors recommend this, including its importance to all of the military, its complexity, its inherently team-based nature, and an ongoing test bed of instructional design and development that exists in the COMET Project of the University Corporation for Atmospheric Research at Boulder, Colorado. This project has developed a massive body of training which is used by a very large international audience. It represents a large and growing design/development activity that likes to partner with special needs. Among the project's sponsors already are the Army, Navy, Air Force, and Marines. The project would

provide an excellent collaborative partner which is able to supply a very large number of participants who represent an appropriate target population and a ready-made distribution system for trying out and iterating research products.

Finally, I recommend the value of a little-known idea which I will call "Spotting Operational Principles" as a theme within the research. The notion of an operational principle was introduced by Michael Polanyi (Polanyi, M. (1958). Personal Knowledge. University of Chicago Press). It focuses the mind on the core essential mechanisms by which an artifact works. Too often in our training we conduct the learner through a forest of details before acquainting him/her with abstract inner mechanisms. Learners are thus not trained to drive to the heart of their knowledge and see learning as the amassing of bulk rather than incisive insight into a handful of defining principles. Teaching learners to search for operational principles will accelerate learning and organize what is learned for long-term retention and independent reasoning and knowledge-extension.

Frank L. Greitzer, Ph.D.
Pacific Northwest National Laboratory

Key Issues

- Defining the ingredients of expertise for a problem domain
  - Breaking down expert knowledge into critical concepts: mental models, associated cues/patterns (within a cognitive engineering/naturalistic decision making approach)
  - Defining conceptual elements that reflect varying levels of expertise; also misconceptions and characteristics of less experienced learners
  - The expert knowledge (ingredients of expertise) needs to be represented in a computational form. Formal ontological languages and knowledge-bases to represent the domain, data, and its axioms are important for reasoning within the domain.

- Developing measures/metrics
  - Identify operative mental models
  - Assess expertise – using the knowledge base.
  - Identify need for mitigation – recognition/inference of the distance between the current mental model and an optimal mental model can be done based on knowledge representation methods/tools; that distance and differences in patterns may be used to develop or apply strategies for mitigation using a different mental model.

Pertinent Theories

- Expertise/Knowledge
  - Naturalistic Decision Making—Recognition Primed Decision Making

- Metacognition concepts—needed to support insight/understanding about misconception or being on wrong track, needing to switch to another mental model for example

- Experiential learning
  - Guided Discovery Learning
  - Problem-based learning
  - Adaptive/Predictive case-based learning

Research Challenges

- Development of sufficiently accurate and detailed knowledge representations to support automated reasoning/intelligent training management

- Knowledge representation should reflect mental models
  - Mental models should be developed that correspond to different levels of expertise

- Mental models also should be defined to represent expected misconceptions and reasoning failures of less experienced trainees

- How to recognize performance associated with a given level of expertise and mental model: A key requirement for accelerating learning is to
  - Recognize mental model being employed in solving a problem (associated with a learning state)
  - Identify observable performance "indicators" associated with mental models

- Apply appropriate training management action based on identified learning state
  - Mitigation (e.g., hints, scaffolding)
  - Adaptable scenarios to increase or decrease complexity based on learning state

Opportunities

- Among numerous examples of domains that require years of "on the job" experience, the electric power industry (generation and transmission) is an excellent potential application domain for R&D on approaches to accelerate expertise acquisition.
- Major challenge for training in this industry… aging workforce, gap between seasoned experts and apprentice/journeyman operators, cultural and background/experience differences , limited funding for training.

Alice F. Healy, Ph.D.
University of Colorado

Optimal training should be efficient, durable, and flexible. On the basis of prior research, we have developed a set of training principles that optimize the speed of training, the long-term retention of trained knowledge and skills, and the transfer of trained performance to new circumstances. The following is a brief summary of some illustrative training principles.

(1) Increasing interference during training has been shown to impede training efficiency but ultimately to enhance the durability and flexibility of what is learned. By the contextual interference principle, interference during learning facilitates later retention and transfer (Battig, 1979; Schneider, Healy, Ericsson, & Bourne, 1995).

(2) It has been shown that many things that make learning difficult facilitate transfer to a new task as well as long-term retention of the original task. By the training difficulty principle, any condition that causes a desirable difficulty during learning facilitates later retention and transfer (Bjork, 1994; McDaniel & Einstein, 2005; Schneider, Healy, & Bourne, 2002).

(3) For optimal performance, the entire configuration of task requirements during training needs to match those in the field as closely as practically possible. By the specificity of training principle, retention and transfer are depressed when conditions of learning differ from those during subsequent testing (Healy, Wohldmann, Sutton, & Bourne, 2006).

(4) If secondary task requirements exist in the field, then such requirement should be incorporated into training to provide optimal transfer to field performance. Likewise, training with extraneous secondary task requirements should not be use if field performance does not include those requirements. By the functional task principle, secondary task requirements are often integrated with primary task requirements during learning, resulting in the acquisition of a single functional task rather than two separate tasks (Healy, Wohldmann, Parker, & Bourne, 2005; Hsiao & Reber, 2001).

(5) Procedural information (knowing how to do something) is more durable than declarative information (knowing that something is the case). However, durable performance lacks generality because performance at test is optimal only when the procedures acquired during training are duplicated during testing. By the procedural reinstatement principle, specificity (limited transfer) occurs for tasks based primarily on procedural information, or skill, whereas generality (robust transfer) occurs for tasks based primarily on declarative information, or facts. Thus, for skill learning, retention is strong but transfer is limited, whereas for fact learning, retention is poor but transfer is robust (Healy, 2007).

(6) Pre-existing knowledge can be used to aid recall of new unrelated facts even when the facts themselves fall outside the domain of previous knowledge. By the strategic-use-of-knowledge principle, learning and memory are facilitated whenever pre-existing knowledge can be employed as a mediator in the process of acquisition (Kole & Healy, 2007; Van Overschelde & Healy, 2001).

(7) Prolonged work on a given task often results in deterioration of performance, despite ongoing skill acquisition. Specifically, prolonged work sometimes produces an increasing speed-accuracy tradeoff in performance, such that accuracy declines over trials while at the same time response speed improves (Healy, Kole, Buck-Gengler, & Bourne, 2004). The deterioration seems to be attributable to task disengagement on the part of subjects. By the cognitive antidote principle, the introduction of cognitive activities can counteract task disengagement effects, resulting in performance maintenance or even improvement during sessions of prolonged work (Kole, Healy, & Bourne, 2008).

(8) Mental practice can serve as an effective substitute for physical practice for both enhancing knowledge of particular sequences and improving general skill. Indeed mental practice might be superior to physical practice under circumstances that promote retroactive interference. By the mental practice principle, mental practice can retard forgetting and promote transfer of training to a larger extent than can physical practice, which suffers from motoric interference (Wohldmann, Healy, & Bourne, 2007, 2008).

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Robert Hubal
RTI International

Main focus is on intelligently implemented simulation-based training/assessment systems that present structured scenarios (cases).

Systems need to:
- Mimic the operational context.
- Precisely monitor user actions -- map against pre-understood performance measures during critical tasks.
- Be parameterized, so as to be able to dynamically construct scenarios:
  o Baseline scenarios for initial assessment against learning objectives.
  o Common and rare scenarios for learning generalized and specialized knowledge and procedures.
  o Instructional tailoring, the introduction of "twists" into scenarios to address proximal learning objectives and biased reasoning -- dependent on performance within recently-completed scenarios.

Systems address skills:
- Skills proficiency is attained through scenario-based acquisition, practice, validation.
  o Proficiency can be attained with good training design and situated learning in a short time.
  o As distinguished from expertise that involves both proficiency and strategic knowledge and adaptability, and typically requires more time to achieve.
- This pertains to a range of skills:
  o Hands-on, well-defined (e.g., operation of C2 systems).
  o Predictive, less well-defined (e.g., weather forecasting).
  o Interactive, often poorly-defined (e.g., human-human interaction).
- Skills retention is achievable through the same sequence of acquisition, practice, validation, though with fewer scenarios needed.

Systems are not single-technology.
- Use a mix of training/assessment environments.
  o Acquisition and much practice usually most cost-effective in a classroom and/or virtual environment.
  o Advanced practice and some validation usually most cost-effective in a constructive environment.
  o Final validation usually demands a live or near-live environment.
- Note: Validation used here as a term indicating the final step in demonstrating skills proficiency. Assessment used here as a test of skills performance.
    o It is important that assessment of skills occurs is contextually-appropriate. It requires demonstration of skills in a reliable, valid scenario.

Harry O'Neil, Ph.D.
University of Southern California

Conceptual Issues
- Retention vs. transfer tradeoff
  - Different instructional strategies and different assessments
  - Transfer has multiple meanings
  - Testing knowledge that has not been explicitly taught (Mayer) vs. testing knowledge that transfers to job setting (Kirkpatrick).

- To accelerate learning with same level of retention
  - ISD (teach less) results in approximately 30% reduction in time.
  - SD plus technology results in an additive percentage reduction (x%).
  - Tailor by prior knowledge people who have knowledge are not taught it.
  - Leverage motivation to accelerate learning

- To accelerate learning with same level of transfer
  - Trade off retention (it will get worse)
  - Manipulate instruction (e.g. varied examples) with more time.

- Skill decay
  - Declarative knowledge is less often forgotten
  - Procedural knowledge is more often forgotten
  - Initial acquisition is best predictor of skill decay

- Feedback matters. Four characteristics of feedback
  - Complexity of feedback
    - What information is contained in the feedback messages
    - Degree of elaboration
  - Timing of feedback
    - When is the feedback given to students
    - In complex learning delayed better than immediate
  - Representation of feedback
    - The form of the feedback presented (text vs. graphics)
  - Frequency of Feedback
  - Slows down the Acquisition of Knowledge but facilitates Transfer of Knowledge

Create Just In Time Learning

- Short slices of instruction (< 5min) targeted to a single concept
- Delivered online using video with narration
- Represent the domain using an ontology
- Estimate what the learner knows about a domain given performance data on assessments and what is forgotten
- Use Bayesian networks to fuse assessment data and infer understanding of domain and topics within domain

o Need Just In Time assessments for Just In Time learning

Another Alternative for Accelerated Learning
- o Teach people to be smarter
- o Goal is to improve cognitive and affective skills of personnel
- o Rationale
- o Effective training is a product of quality of instruction and trainees with effective learning strategies
- o Many trainees lack learning strategies

Measurement Challenges
- o Performance assessment
  - o Lack of psychometrics for Simulation/games

- o Questions
  - o How is difficulty estimated?
  - o How many tasks are needed?

- o Live with the reality that performance assessment and time constraints lead to few tasks. Conduct generalizability studies.
- o What is role of gender, ethnicity, and prior experiences?
- o Best strategy to develop for useful, valid, fair and feasible measures?
- o Should constructs be reported as single vs. multiple scores as profile and/or levels?

Research Recommendations
- o Create test beds for cost-effectiveness studies
- o Augmented cognitive load theory with improved measurement and motivation
  - o John Sweller-UNSW
- o Research for teams accelerated learning
  - o Create software pipeline from Basic Training to A-Schools to C-Schools to fleet
  - o Diagnostic/prescriptive system
- o Just in time instruction and just in time and right sized assessment in context of training pipelines.

Cognitive Load Theory
- ▪ Intrinsic cognitive load: depends on the extent of element interactivity of the materials or tasks that must be learned (van Merriënboer & Sweller, 2005; Paas, Renkl, & Sweller, 2003)
- ▪ Germane cognitive load: associated with processes a learner engages in that are beneficial for learning (Sweller, van Merriënboer, & Paas, 1998)
- ▪ Extraneous cognitive load: caused by mental activities during learning that are unnecessary and so interfere with schema acquisition and automation (Paas, Renkl, & Sweller, 2003)
- ▪ Learning material should be designed to minimize extraneous cognitive load and optimize germane cognitive load (Cooper,1998; Sweller, van Merriënboer, & Paas, 1998).

Robert Patterson, Ph.D.
Washington State University

(1) The cognitive psychology literature, in my view, is convincing in showing that humans possess a capacity for learning and acquiring knowledge about the statistical structure of dynamic events and episodes as they go about their lives--i.e., the conditional probabilities, joint probabilities, and raw frequencies of temporal patterns across dynamic scenes.

(2) This learning can be 'unsupervised' and passive in the sense that individuals learn such dynamic statistical structures in the absence of an intention to learn, in the absence of instructions as to where to direct attention, and in the absence of feedback from their environment.

(3) Although this issue is controversial, it does seem to me, and many other researchers, that much of this information is implicit and tacit in the sense that it is very difficult, if not impossible, to verbalize fully.

(4) The acquisition of early language by human infants is likely to be based on this process.

(5) This process is likely to be formally equivalent, if not the same, as the processes underlying associative learning (e.g., Pavlovian and operant conditioning).

(6) This kind of implicit learning is very likely to be one of the foundational processes underlying intuitive decision making (as discussed by Gary Klein and others in the literature).

Thus, my question is: Is this process of largely implicit learning of spatio-temporal statistical structures occurring, in parallel with other kinds of learning, in the kind of skill and knowledge acquisition of which members attending the workshop are interested. I believe that this is likely because I highly doubt (though not impossible) that such a 'primitive' process would be turned off when one engages in more explicit types of skill and knowledge acquisition. In other words, when weather forecasting, for example, are the forecasters relying upon implicit knowledge of the spatio-temporal correlations of cues and patterns in addition to their explicit knowledge of physics?

Robert Proctor, Ph.D.
Purdue University

As part of the study of acquisition and retention of skill, it is important to understand how training and practice influence fundamental information-processing components. Such understanding can be gained from use of basic tasks that isolate perceptual, cognitive, and motoric components of skill. One advantage of basic tasks is that learning occurs quickly and careful manipulation of variables allows characteristics of the skill components to be discovered.

As an example, much of our research has focused on transfer of newly acquired associations in tasks that require a rapid choice response to a stimulus. In the prototypical procedure, a two-choice reaction task of pressing left and right response keys mapped incompatibly to stimuli in left or right locations (e.g., press "left" key to a stimulus that appears on the "right") is first performed. This is followed after a delay by performance of another two-choice reaction task in which subjects respond to a nonspatial stimulus attribute (e.g., color; the *Simon task*) and stimulus location is irrelevant. Thus, the spatial mapping used in practice is task-irrelevant in the transfer task. Without such practice, responses are faster and more accurate when the stimulus and response locations correspond, which defines the *Simon effect*. However, after performing the incompatible-mapping task, the advantage of the spatially compatible responses in the Simon task is eliminated. This outcome implies that subjects acquired incompatible stimulus-response associations and transferred them to a subsequent task even though they were no longer relevant.

Through manipulating several variables, we have found that:
1. The incompatible stimulus-response associations are retained for at least a week.
2. The strength of the associations, as implied by the magnitude of the transfer effect, increases as the amount of practice trials increases.
3. These associations have both modality specific and general components, as practice with auditory stimuli produces some transfer to a visual Simon task.
4. With extended practice, more abstract rule-like procedures are acquired that generalize, for example, across different spatial orientations.
5. Practice with left and right pointing arrows transfers to stimuli varying in left and right locations, and vice versa, implying reliance on common visuospatial codes.
6. Arrows also show some indication of producing transfer to location words (and vice versa) after more extended practice, whereas spatial locations do not, suggesting that arrows also activate verbospatial codes common to verbal stimuli.
7. No reduction in transfer occurs when perceptual features of response devices used in the practice and transfer sessions are altered, but significant reduction occurs when responses are executed differently (by pressing keys with two hands or moving an index finger to a response key) in practice and transfer sessions. These results suggest that motoric or procedural components are more salient than perceptual components.

Basic tasks of this type can be used to investigate and test characteristics of learning. The results can be used to develop and test quantitative and computational models of skill acquisition, retention, and transfer for predicting training effectiveness.

Karen Velkey
Northrop-Gtumman

Key Issues in Expertise and Retention of Learning and Expertise:

- Ability to quickly make deep and meaningful connections between previous learning and new or novel situations.
    - o I think this requires "deep" learning of the original concepts and repeated and deliberate practice in making those connections.
- Do we teach people how to be mentors and/or give them specific tools to share their expertise in a meaningful way?
    - o We may not be giving learners the best opportunity to become experts if we don't also train mentors and experts in helping that person learn. It seems like many mentorship programs rely on a "watch and learn" mentality where the deeper knowledge of the mentor may not be obvious.
    - o I have found over the years that the most experienced and knowledgeable people often do a terrible job of describing what it is they do. Simply put, they are experts because they make the job look "easy". They may need training to really be able to express the complexities of their job that have become second nature.
- Do we reward / recognize people for the mentoring aspects of their work? That is, do we reward them based on how well their mentees perform?
    - o Many experts have been rewarded over long careers for being the expert and sometimes THE expert in a particular area. Making the transfer of that data a rewarding experience both personally and professionally could be important as well.
- It seems that we have to allow, and even insist, that people learn in a variety of ways and be able to translate that learning into as many relevant contexts as possible.
- Is there value in teaching novices how to be mentors? So, not only teaching them the skills in which we desire them to become experts, but teaching from the very start how to describe the skills they are learning and share knowledge with others.

David Ziebell
Electric Power Research Institute

The critical expert is an Agent of the socio-technical entity (as opposed to journeyman) as a cognizant in the socio-technical entity.

Assume the relevant socio-technical entity is an adaptive system within an ecology of adaptive systems, assume truth of the notion of 7 elements of adaptive systems, "Agent" is an adaptive individual with power (connection, authority) over the larger system (this is a proposed definitional notion).
Contrast with mindfulness and decision-making in which the journeyman cog's mindfulness is about the task and the environment and the decisions are localized, merely homeostatic with respect to the larger entity's purpose/mission.

The expert Agent, however, has awareness about the larger entity, and can change the mission, re-configure the entity, perhaps even cause the entity to navigate the environment. Analogy with the default mode function/executive function of the brain (self-consciousness vs. consciousness).

Is a hiatus from duty (for an expert Agent) similar to unplugging/disconnecting the default mode function in the brain? If so, the problem of re-immersing after a hiatus may be more one of re-connection with an evolved entity and less the notion of rebuilding skills.

Towards methods at this level: Disconnection is not really sleep, but perhaps dreams as "serious games?") Examples in industry: Special Projects VP, relay protection asset manager, distribution system chief district operator. Seen from the perspective of the individual's lifespan/career, the change from cog to agent is not a developmental phase so much as a transformation. Novice/journeyman/master progression as private victories, becoming an agent is a public victory (after Covey).

Selection criteria for prospective "agent" may be different? What is the antidote for the Peter Principle? Does this systems view provide a basis for a better differentiation between "resilience and adaptivity?" Homeostatis and stability provide near term continuity, at the point of the spear "adaptivity" is valued as being the ability to react to environmental insult and still complete the given mission.

But true creativity (where the Agent works at the socio-technical entity level) involves stability into the future, growth, evolution in a co-evolving ecology. This is more than homeostasis, it is life and the procreation of the American way. Requisite imagination in the war on terror?

Contrast "two kinds of transfer" with "transfer" vs "transformation of scope." Need a better way to say this (the notion or transformation to agent, which may be a "law of nature" at a level of

complexity that human beings normally don't experience directly.) This transformation may be akin to a peak experience, in which all of one's tools, knowledge, experience, and environment feel like extensions of one's body – the pilot is the airplane and the airspace and the bullet? The chief district operator is the procedures, the control room, the manhole and the electrons? Something similar to this transformation may be applicable at the cog level as a marker of the transition from person-as-asset to person-as-leader or some such.

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FORMAL PRESENTATIONS

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Accelerated Learning and Long Term Retention of Expertise

9 Oct 2009

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2

Tasking & Definition

-- DSTAG Tasking --

"The Human Systems team should baseline the existing programs (understand current/planned investments including cognitive techniques) and identify new ideas/technologies to be pursued."

What is "accelerated learning" ?

-- The TFT's Definition --

Any learning system or environment that attempts to control for *time* spent versus *content* learned with the following goals:

- Faster attainment of skill and knowledge then a current baseline, and increase in on the job performance with better retention of learning
- Quickly assimilate and convert to training content battlefield lessons learned

AL GOAL = Optimize Options in a Learning Acquisition TRADESPACE
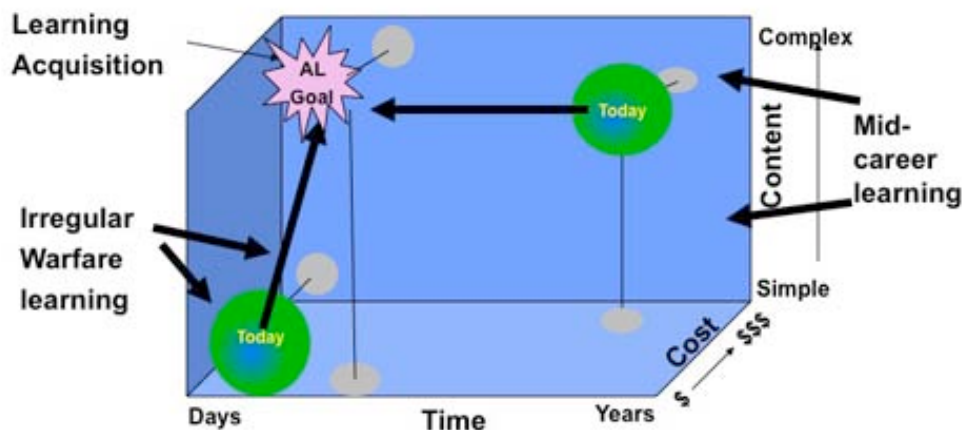
The Accelerated Learning Challenge

Current Warfighters are required to perform tasks for which they may not be well trained, when time is of the essence.

Interpersonal skills in Irregular Warfare (IW) /Counter Insurgency Operations (COIN)/ Security, Stability, Transition, and Reconstruction Operations (SSTRO) (the cultural chameleon)
  - Achieving and making use of societal and cultural awareness

Dynamic planning/replanning in IW/COIN/SSTRO contexts
  - Kinetic battlespace skills
    - Maritime battlespace management and the prevention of mutual interference in coalition ops
  - Non-kinetic knowledge development and analytic skills for Diplomatic, Information, Military and Economic (DIME) /Political, Military, Economic, Social, Information and Infrastructure (PMESII) context
    - In real-time Brigade ops planning -- evaluate, assimilate, and act in both the physical and civil (political, cultural, and economic) environments of the battle space leveraging non-military organizations

Real-time situational understanding in IW/COIN/SSTRO operations
  - Determine the military implications of fused intelligence indicators, all source information, orders of battle in the context of DIME/PMESII
    - Develop options in AOC's in context of "whole-of-government" engagement

5

Key AL S&T Challenges that are Minimally or Not Funded

- Understanding the requirements for proficiency and how to accelerate its attainment

- Understanding how to increase retention of competence – "accelerated retention"

- Making practical serious games for use in AL

- Developing technology for rapid understanding of learning problem e.g., rapid cognitive task analysis

- Determining level of competence required for different stages of a war fighter's career

- Calculating the cost-benefit of implementing AL

6

Accelerated Learning Principles

Routine practice is not sufficient for acceleration of competence. There needs to be:

- A constant "stretching" of the skill, defined by increasing challenges (tough or rare cases)

- High levels of intrinsic motivation to work on hard problems

- Practice that provides rich, meaningful feedback

- Practice based on mentoring

- Provisions for individualized/tailored practice due to unique learning styles of each learner

7

Example Accelerated Learning Techniques from Cognitive Science

- Optimal spacing of materials
  - Spaced is better than massed practice (Kornell & Bjork, 2008; Dempster, 1989; Melton, 1970; Rohrer & Taylor, 2006)
  - Optimal spacing: present enough repetitions so that material is mastered, but overtraining is an inefficient use of time
  - Optimal spacing depends on how long material should be retained for – optimal ISI interval = 10-20% RI interval (Rohrer & Pashler, 2007)

- Using tests to improve learning, not just assessment
  - Advantage of study-test over study-study (McDaniel, Roediger, & McDermott, 2007)
  - The importance of active retrieval for learning (Karpicke & Roediger, 2008)

- The benefits of self-explanation (Chi, 1996, 2000)

- Directed comparison for revealing deep principles (Gentner & Namy, 2004; Loewenstein, Thompson, & Gentner, 1999; Rittle-Johnson & Star, 2007)

8

Sample Training Guidelines for Developing Proficiency

Competent performers know a lot. Their knowledge is highly contextual.	Training must provide increasingly detailed knowledge, procedures, principles, in context, with progressive refinement as expertise develops.
Competent performers' knowledge is structured.	Provide suitable knowledge structures early in training.
Competent performers knowledge / skill is compiled and proceduralized	Provide sufficient practice for experience to be compiled.
Competent performers can work forward from underlying principles or backwards from the end goal. It depends upon the case.	Provide underlying principles as part of the knowledge structures. Provide unstructured end-goal exercises only after principles have been learned.
Competent performers can examine a broad range of alternatives or explore a single alternative deeply.	Practice environment must provide for many alternatives and must model them correctly.
Competence keeps developing even after many years and thousands of opportunities for deliberate practice.	Provide journeyman-expert practice environments through simulation and carefully designed exercises.

First Generation in AL
-- an Example of Accelerating Competence --

Adaptive Thinking: A key battlefield thinking skill—making adjustments in an unfolding plan under dynamic conditions of military operations.

Activities Specifically Designed to Improve Performance

- Identify desired elements for expert form
- Learner performs while attending to element
- Coach notes discrepancies from expert form
- Behavior is repeated until habitual
- Performance without attending to expert form

Expert Cognitive Behaviors

- Keep a focus on the mission and higher intent
- Model a thinking enemy
- Consider effects of terrain
- Use all assets available
- Consider timing
- See the big picture
- Visualize the battlefield
- Consider contingencies and remain flexible

Classroom   Distributed (Internet)   Instructorless (DVD/Internet)

Captains in Command

1. Students receive training on the expert Themes of Battlefield Thinking and observe model behavior.

2. Students view a 3-5 minute theme-based vignette that presents a complex and rapidly changing tactical situations.

3. Students are asked to apply their tactical knowledge to think adaptively and list their key considerations.

4. Students view a 3D coach or live instructor discussing expert considerations pertaining to each of the battlefield thinking skills.

5. The students are prompted to evaluate their response based on expert considerations and respond to coach's questions.

6. After covering each of the eight themes, students are provided feedback to his or her responses.

Measurement of Adaptive Thinking

Percent of Critical Information Identified (by Rank)

Same approach can be used in USMC, USN, and USAF
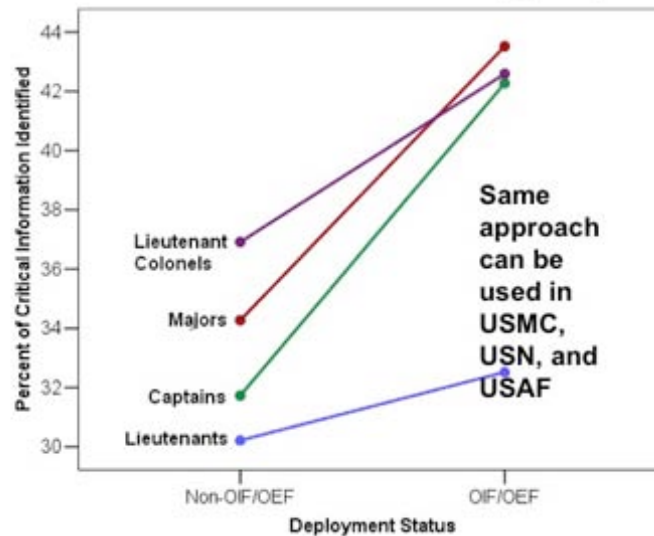
Think Like A Commander & Captains in Command Training

Recent evidence indicates that TLAC and the Captains in Command training develop key battlefield thinking skills comparable to those exhibited by CPTs with OIF/OEF experience

Mean Percent of Critical Information Identified

Legend:
- Captains in Command
- Baseline (Deployed)
- Think Like a Commander
- Baseline (Non-Deployed)
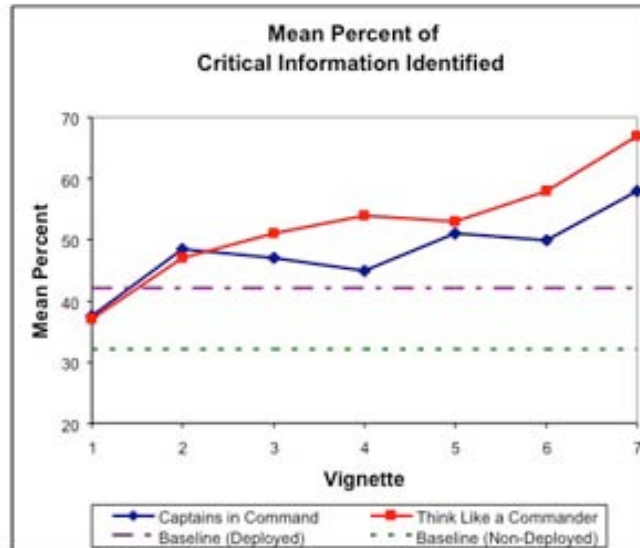
-- an Example of Accelerating Competence --
Adaptive Thinking Training "Think Like a Commander"

Thinking that supports:

making adjustments in an unfolding plan under the dynamic conditions of military operations.

Specific Training Task

The ability to rapidly and accurately 'size up' tactical situations: identify important considerations, risks, key information, alternative actions, potential higher-order effects, and other factors that may be significant in decision making during execution.

J. Lussier, 2008

Goals of the Workshop

The objective of this effort is to create a design and roadmap for investigations aimed at developing robust and broadly-applicable methods for:

(1) Accelerating the achievement of proficiency in USAF mission-critical specializations (and   analogous domains in the private sector), and

(2) Facilitating the retention of knowledge and skill, especially for military personnel who must   take long hiatuses from their domain of primary expertise in order to fulfill other military requirements.

15

8:45 AM	Welcoming Introductions and "Lightning Round" Each participants has three minutes to convey their focus area and their key ideas of hot buttons in issues of training, transfer and retention.
9:45 AM	Presentation 1 Dr. Dee Andrews Identifying Interesting and Viable Research Challenge Questions About Acceleration and Retention • Military Environment • Long-Term Retention Study • Program Roadmapping • DoD Accelerated Learning Study
10:15	Full Group Discussion
10:30 AM	Break
10:45AM	Presentation 2 Paul Feltovich and Robert Hoffman Acceleration and Retention: Research and Theory
11:30 AM	Presentation 3 Acceleration and Retention Issues Lt Col Gina Hilger, USAF Intelligence-Surveillance, Reconnaissance Requirements
12:15	Lunch

16

1:15 PM	Presentation 4 Acceleration and Retention Issues David Ziebell (EPRI) Infrastructure and Power Distribution Domains
2:00 PM	Full Group Discussion
2:15 PM	Presentation 5 Acceleration and Retention Issues Bomber Operations Col Daniel Walker , AFRL
3:00 PM	Break
3:15 PM	Three Break-Out Groups • Selection of Domains
4:45 PM	Break
5:00 PM	Full Group Discussion: • Research Design and Methodology Considerations • Closing comments and Look-ahead at Agenda for Day 2
7:00 PM	Group Dinner at Tia Rosa's

8:30 AM	Breakfast
9:15 AM	(Re)framing based on Day 1 results
9:30 AM	Acceleration and Retention Issues Pilot Transition Training Lt Col Doyle Turner, USAF
10:00 AM	Break
10:15 AM	Three Break-Out Groups • Selection of Domains • Research Design and Methodology Considerations
11:15 AM	Break
11:30 AM	Acceleration and Retention Issues F-16 Retention Research Dr. Winston Bennett

12:15	Lunch
1:15 PM	Acceleration and Retention Issues Dr. Kevin Gluck (with Dr. Tiffany Jaztrzembski) Predictive Performance Optimizer
1:45 PM	Three Break-Out Groups • Challenge Questions for Research
2:30 PM	Break
2:45 PM	Full Group Brainstorm • From Challenge Questions to a Research Roadmap
3:45 PM	Break
4:00 PM	Full Group Brainstorm • From Challenge Questions to a Research Roadmap
5:00PM	Closing Discussion: Look ahead Acknowledgements

19

Distributed Mission Operations Training Research: Skill Retention and Decay Study 1 Results

Results

9-10 October 2009

Winston "Wink" Bennett, PhD
711th Human Performance Wing
Human Effectiveness Directorate
Air Force Research Laboratory

Fighter Combat Training and Management

- **Expertise in this environment depends.....**

- **No formal metric for expertise**
  - Flying hours typical metric – 500 hours in fighters = combat mission ready
  - School/training pedigree
  - Weapons school is considered "Graduate School"

- **Development paths to "Full-up Round" varied, formalized**

- **Mix of professional and ad-hoc training and experience**

- **Sophisticated career path and management**

- **Tracking in and out of flying with formal reconstitution**

2

The Problem[1,2,3]

- *Lost apprenticeship* – fewer opportunities to develop expertise
- Training requirements outpacing capacity/opportunities to train
- Training to gain/maintain readiness is a growing concern
  - Aging systems and hi ops tempo limiting live training opportunities
  - Range limitations reducing fidelity of live training
  - High costs and complexity of missions increasing costs
- Cross-domain integrated training (air, space, and cyber) not realistic
- Formal education and training system trapped in 1985 (*on a good day!*)
- Challenge: Are there mixes of approaches and technologies for training that impact decay and retention of skill and expertise?

1: HQ Air Force (2009). *Live, Virtual, Constructive Concept of Operations* (Draft, June, 2009). Washington DC.; 2: Office of the Under Secretary of Defence (2008). *Joint warfighting science and technology plan*. Washington, DC.; 3: Department of Defense Research and Engineering (2007). *Strategic plan*. Washington, DC.

3

Framing Our Research: What We're Trying to Do
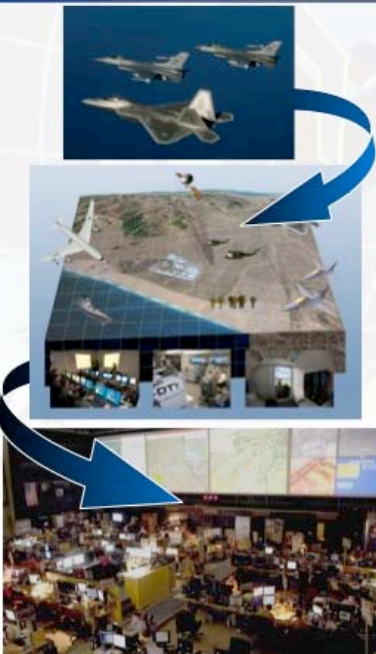
Improve airman performance and readiness through development and application of human learning, instruction, and performance assessment science and technology. *Key characteristics ....*

- *Adaptive* to learner needs
- *Instructionally* and *operationally rich*
- *Routinely accessible* to warfighters
- *Seamlessly integrated* with live systems for continuous learning
- *Generalizable* across missions, common approaches, methods, and data
- *Sustainable* with warehoused knowledge and managed events

4

317

Examining Retention, Transfer, and Decay *in the Wild*

- Wicked hard stuff to do in this content domain
- Lots of things competing with research agenda
- Threats to validity are pervasive
- Community interest is strong but fractured
- Interesting learning and expertise dynamics
- Difficult to determine what constitutes expertise when
- What does acceleration mean in this context
- When do you have it, how do you get it, how do you keep it, how do you lose it

Is "Decay" REALLY "Decay"
If you can recover it quickly - was it ever (really) "gone"?

Research and Development Innovation: Skill Retention and Decay Study

- **What S&T gaps are we addressing?**
  - Limited applied data on air combat skill decay
  - Quantifying factors that may moderate decay
  - Identifying what remains stable/decays over time
- **What we've done:**
  - Longitudinal, experimental study with operational pilots
  - Manipulated retention interval (3 or 6 months)
  - Examined initial training gains, skill decay, skill reacquisition rate, and moderators of skill decay
- **What impact can the S&T have?**
  - Inform frequency of DMO training requirements
  - Identify what skills decay faster than others – shelf life
  - Quantify potential moderators

6

Methods & Measures

- Longitudinal study using operational F-16 pilots

- Initial 5-day DMO structured training visit, followed by a 2-day return DMO training visit. Demographics captured each visit

- 3 or 6 month retention interval

- Equally complex, mirror-image point defense missions flown at beginning and end of first and second visit

- Performance assessed using objective measures

  - Mission outcomes: strikers to target, enemy aircraft killed, friendly mortalities, weapon hit ratios, Top Gun, etc.

  - Process/skill measures: Time in vulnerability regions (e.g., MAR, N-pole), weapons employment measures (e.g., ranges, mach, loft, F-pole, etc.), comm coordination (e.g., voice overs), etc.

7

Expectations

- Initial week training gains will be consistent with findings from AFRL's DMO within-simulator training effectiveness baseline study

  - There should be significant improvement in performance during the five days of initial training

- There to be some skill decay during the retention interval

  - The amount of decay should depend on the length of the decay interval, i.e., the 3-month group should demonstrate less skill decay than the 6-month group

- Both groups should show significant improvement in performance during the refresher training - ideally recovering to the level of skill attained during the initial training, or possibly exceeding that level

8

DMO Skill Retention Study: Procedure

Teams 1&2 Initial Training

Team 1 Final Reassessment

Team 2 Final Reassessment

3 Month Retention Interval

6 Month Retention Interval

- F-16 Pilots were allowed practice runs with the simulator for an hour.

- Pilots were then "benchmarked" or tested on their air-to-air point defense scenario performance on Monday, then tested again on Friday. Five-day initial syllabus

- Pilots were then tested twice on their 2-day return trip either three or six months later

Anticipated Skill Retention Results

Percent improvement from baseline

Residual decay

Baseline

— Training gain
— After 3 month decay interval
— After 6 month decay interval
— Expected end performance

Retention interval

Initial Training — Pre / Post

Refresher Training — Day 1 / Day 2

Timeline (not to scale)
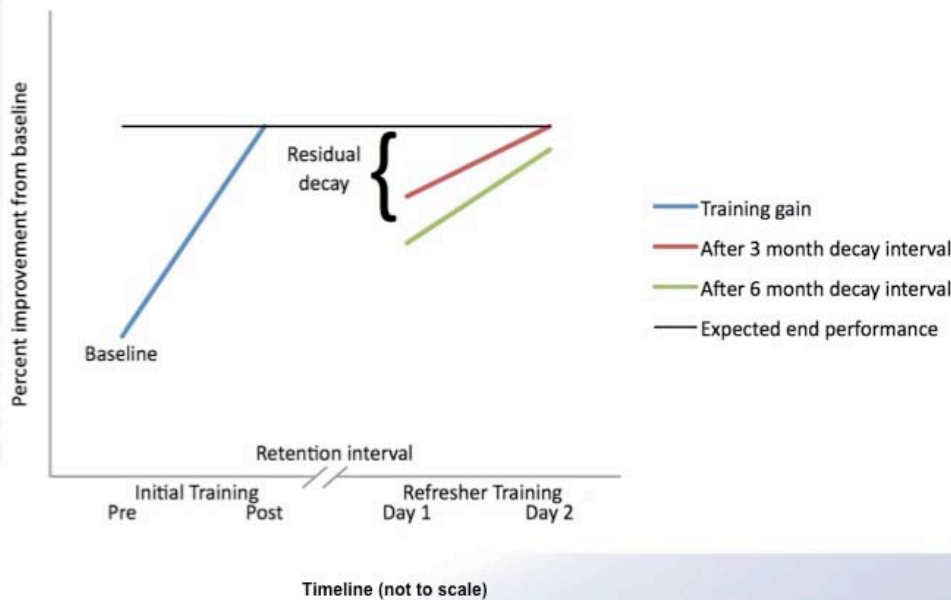
Anatomy of Example Scenarios

MEC Definition/Validation
- MEC Analysis (developmental experiences and training emphasis areas illuminated)
- Event design is framed by these developmental experiences
- Map experiences back to Knowledge and Skills (K/S's)
- Fly out and ensure trigger events tap K/S's
- Incorporate into syllabus with elaboration and deliberate practice approaches

Event 1

Experiences – Daytime/supersonic employment, operations against threat w/chaff/flare, radar search, targeting responsibilities, 1:1 force ratio
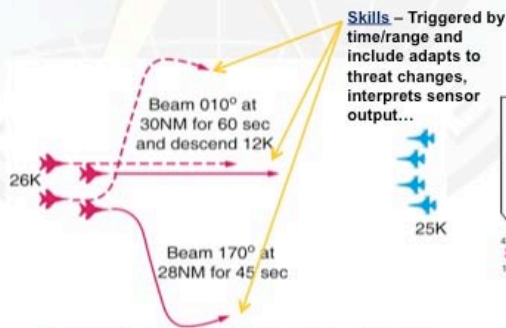
Skills – Triggered by time/range and include adapts to threat changes, interprets sensor output…

Beam 010° at 30NM for 60 sec and descend 12K

26K

Beam 170° at 28NM for 45 sec

Knowledge – Commit criteria, comm standards, engage criteria, formation, ROE, threat capabilities

Event 2

Experiences – Previous scenario plus a full range of adversary threats, task saturation, operating area restrictions, 1:3+ force ratio
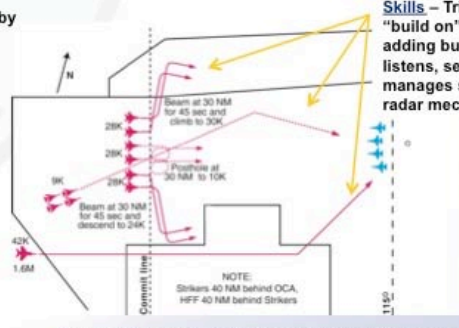
Skills – Triggers here "build on" previous adding builds picture, listens, selects tactic, manages stress, radar mechanics

Knowledge – Previous scenario plus follow-on options, friendly capabilities, package composition, mission phases

11

Demographics

Participant demographics, 3-month group

Rank	N	Avg. age	Avg. years of service	Avg. F-16 Hours
First Lieutenant	5	26.2	4.5	241.3
Captain	14	31.4	8.4	819.0
Major	5	36.0	15.2	1201.6
No rank identified	4			1340.5
Total	28	31.3	9.0	884.2

Participant demographics, 6-month group

Rank	N	Avg. age	Avg. years of service	Avg. F-16 Hours
First Lieutenant	4	27.5	5.0	237.3
Captain	21	29.5	8.2	668.3
Major	10	36.1	14.5	1307.6
Lieutenant Colonel	6	38.8	18.5	1876.9
Total	41	32.3	10.9	959.1

12

SOME SELECTED OUTCOME MEASURES FOR CONSIDERATION ….. JUST A TASTE

Study Completed, Other Analyses Are In Progress

Enemy Strikers Reaching Target
Data From18 teams (72 pilots)
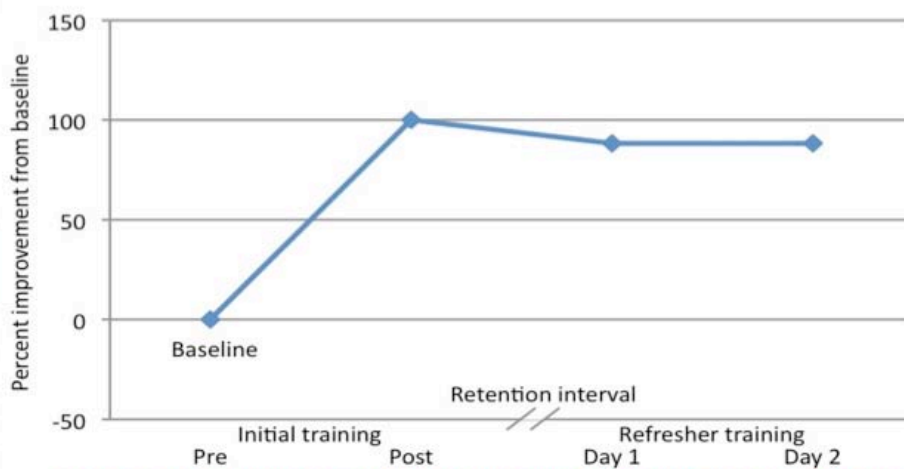
This is an outcome measure: How many bombers are killed before bombing a friendly target

! Performance improved during initial training, decayed somewhat over the retention interval, and remained relatively constant during refresher training. Only the initial training gain was statistically significant in the MANOVA analyses

Top Gun Score
Data From 18 teams (72 pilots)
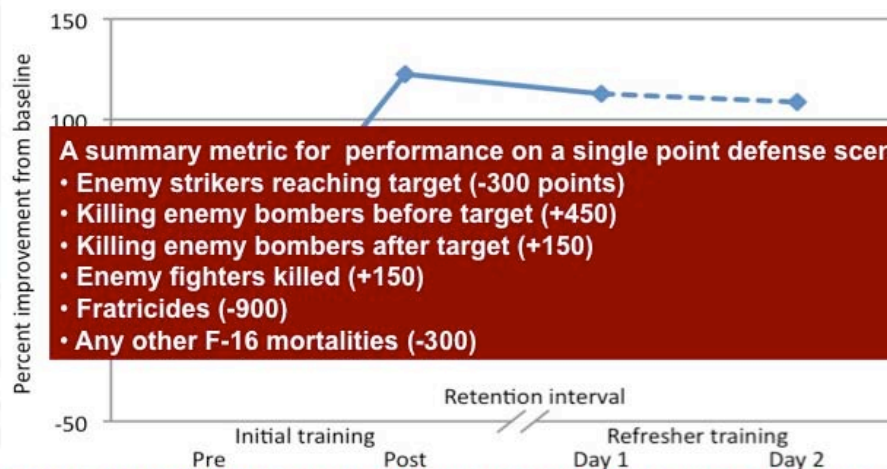
A summary metric for performance on a single point defense scenario
• Enemy strikers reaching target (-300 points)
• Killing enemy bombers before target (+450)
• Killing enemy bombers after target (+150)
• Enemy fighters killed (+150)
• Fratricides (-900)
• Any other F-16 mortalities (-300)

This is outcome measure: A composite score for how well they did based on a predetermined set of scoring criteria (Range is -1800 to +1800 points)

! Performance improved during initial training, decayed during the retention interval, and unexpectedly continued to decay during refresher training. Only the initial training gain was statistically significant in the MANOVA analyses

15

Mach at Pickle
Data From 18 teams (72 pilots)
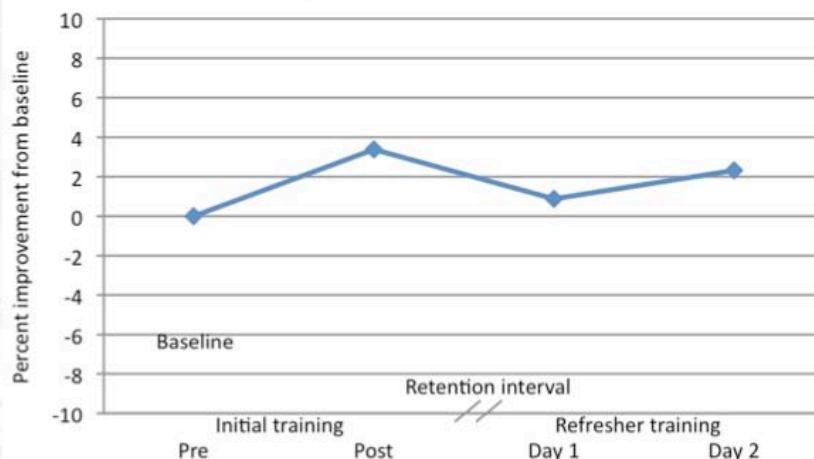
This is a process measure: The speed of the jet at time of missile launch

! There is little absolute change in this metric during initial training, retention interval or refresher training. MANOVA analyses did not reveal any significant changes. However, the differences observed are worth more explanation due to the importance in actual combat (i.e., practical significance)

16

Some Initial Conclusions

- First week of study replicated findings from previous within Simulator Study – Large DMO training week effects
- Some evidence of Skill Decay across retention period
  - Likely retention period impacts on decay
  - Pilot level of experience moderated skill decay (Hi experience)
- Results statistically weaker than desired
  - Small sample size provided very weak statistical power
  - Team performance on an extremely complex and dynamic task
  - Some circumstantial evidence that teams may have known the benchmarks they were going to fly
  - Other mitigating variables not tracked
  - Flight lead experience may be mitigating <u>overall </u>team decay
- Analyses show decay at the team level, analyses need to be conducted to investigate individual level decay (e.g. crank mechanics)

17

Design Limitations

- Current study designed as a very <u>conservative</u> test for skill decay

  (Seemed like a good idea at the time!)
- Factors making study conservative:
  - Highly experienced pilots
  - Most experienced pilot flew as lead
  - Used performance for stable teams of pilots, less likely to have team cohesion 3 or 6 months later in reality
  - Pilots receive continuous training, so retention intervals had variable additional training
  - Good argument that no change (null effect default) is possibly not the best statistical test. Some degree of improvement should be used
  - Used benchmark tasks that were performed near ceiling at end of training week, i.e. assessments did not map full range of skill levels

18

Lessons Learned For Future Study

- Need larger samples for this kind of study

- Greater experience range with content domain

- Additional retention intervals

- Must track what happens in the retention interval - clearly practice and refreshing was ongoing – we attempted to track this experience, but …..

- Develop several sets of pre- and post-test scenarios that are not part of regular research weeks

- Examine other metrics that might be more sensitive (e.g., shared understanding, tactical knowledge)

- Variety of outcome and process measures in our data set still being examined

19

Some Closing Thoughts

- Research of this kind is crazy hard, but very important

- Two combat theaters compete for subjects and impact schedule

- Examining training alternatives and their immediate and longer term impacts of expertise and retention is critical

- Accelerating competence (expertise) only works if the environment supports and promotes growth

- Accelerated learning interventions must be systemic
  - Point solutions will not be effective in the absence of opportunities to practice and extend knowledge/understanding
  - Monitoring/tracking mechanisms must be part of solution

! Effective training may not be efficient, and vice versa in terms of developing/sustaining/growing expertise

20

Thanks a Bunch!
Questions?

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Predictive Performance Optimizer

10 October 2009

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Outline

I. **Historical Background**

II. Approach and Validation

III. Predictive Performance Optimizer

IV. Future Directions

1994

• Stat Lady

• SMART Algorithm

(Student Modeling Approach for Responsive Tutoring)

Shute, V. J. (1995). SMART: Student Modeling Approach for Responsive Tutoring. *User Modeling and User-Adapted Interaction*, *5*, 1-44.

- **Decomposition of learning curve (Masters thesis)**
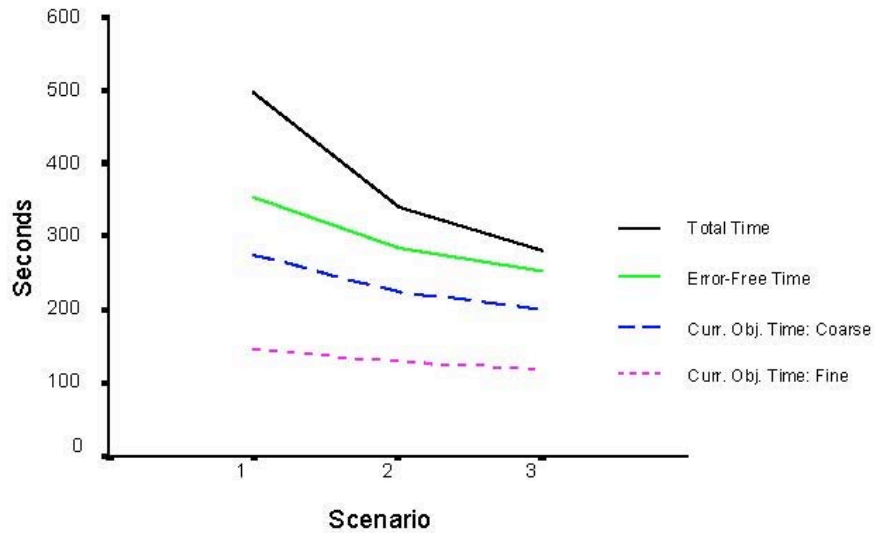
- **Dissertation – eye movements and algebra tutoring**
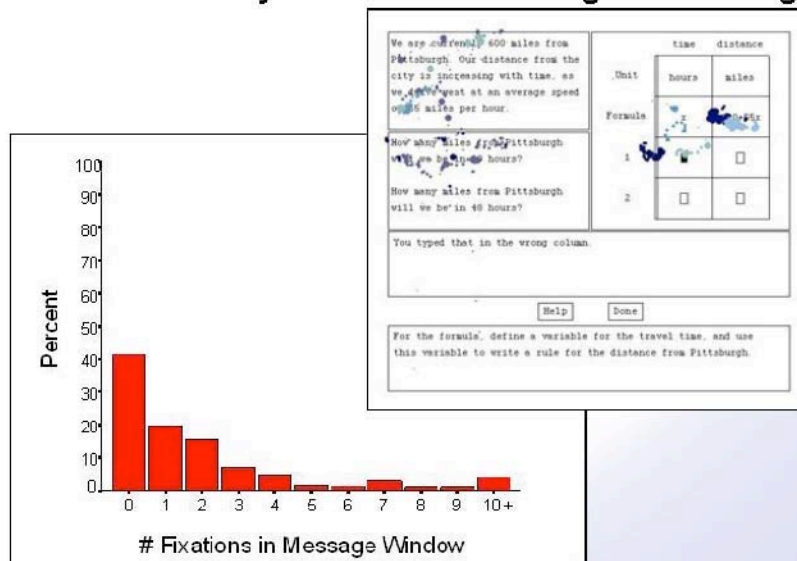
• Arrived at the Mesa Research Site

7

Cognitive Tutors™

8

Can We Use the Cognitive Tutors ® as Cognitive "Trainers"?

- Successfully used in algebra educational

- Cognitive skill represented as production rules

- Mastery estimate is adaptation of Bayes' theorem

- Assumes a 2-state learning model.

- Probability that a rule is in the learned state following nth opportunity to apply that rule:

$$p(L_n) = p(L_{n-1}|\text{evidence}) + (1 - p(L_{n-1}|\text{evidence})) * p(T)$$

$$p(\text{learned}) = p(\text{learned last time}) + p(\text{not learned last time}) * p(\text{transition})$$

9

Limitations of Cognitive Tutor™ Approach

- Does not account for skill/knowledge decay
  - Once learned, it is assumed learned forever
  - OK (perhaps) for tracking short-term learning in educational domains
  - Not good for predicting long-term performance profiles in military training domains

- Does not predict response times
  - Not mapped to retrieval latencies or cognitive cycle time
  - OK for static educational domains
  - Not good for time-critical military domains

10

331

2004 – Proposed Alternative

- A general equation for learning and forgetting (Anderson & Schunn, 2000):

$$\text{Performance} = A * N^c * T^{(-d)}$$

    A = Scaling parameter

    N = Amount of practice

    c = Learning rate

    T = Time since learning occurred

    d = Decay parameter

- Equation provides reasonable fits across different delays and tasks (see examples)

Memory for Street Names

Bahrick et al. (1983): Table 8

R = .985
RMSD = 4.77%
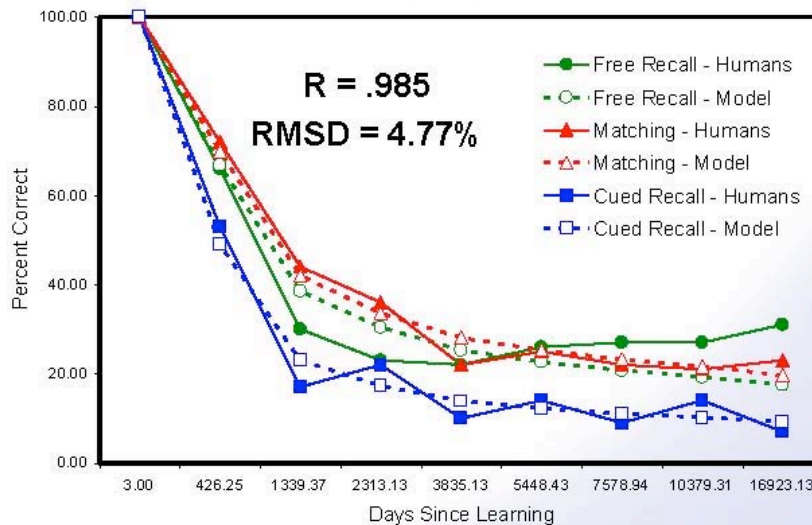
Relearning Nonsense Syllables

Ebbinghaus (1885/1964): Chapter 7

R = .923
RMSD = 3.24%
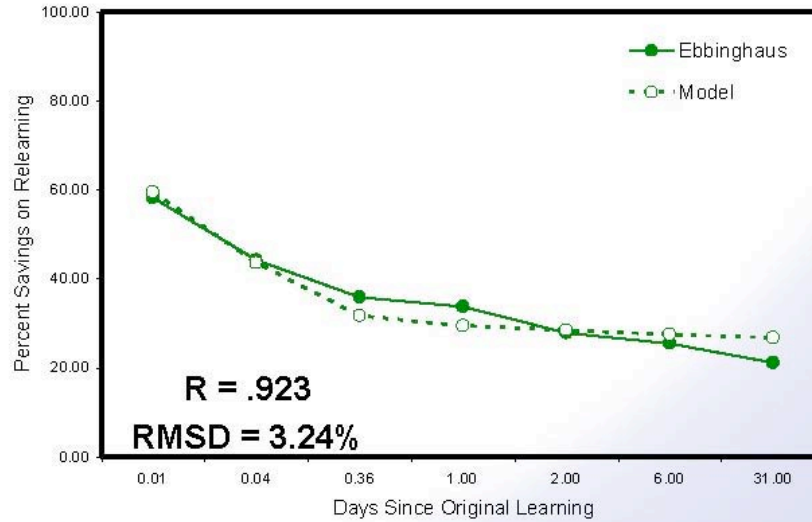
Relearning Sequential Control Operations

Ammons et al (1958): Figure 3

R = .956
RMSD = 1.91%
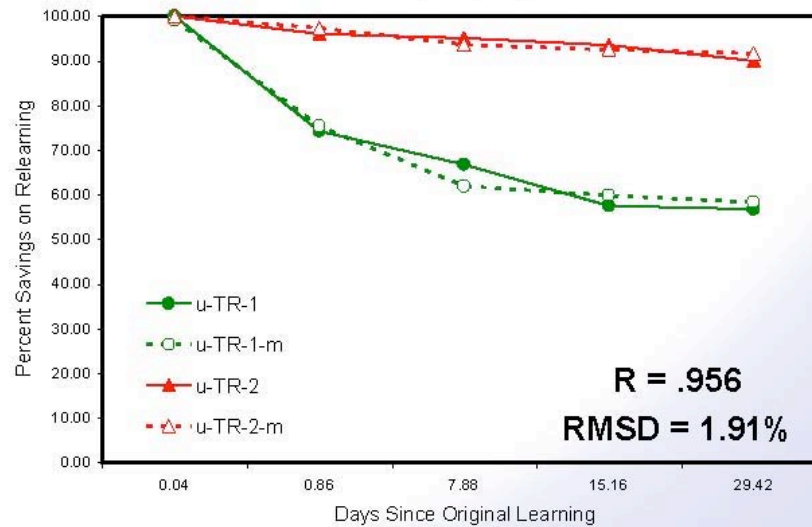
Challenges to this Approach

- Simple performance equation does not account for distribution of training over time
  - All learning is assumed to occur at T=0

- However, training is always distributed to some extent, and many times distributed across days, weeks, or years
  - Spacing effect

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2005 – Began work on incorporating the spacing effect

- Leverage over 100 years of research in experimental, mathematical, and cognitive psychology

- Showcase new innovations *(a priori predictions and principally-guided prescriptions)* over existing state-of-the-art *(Anderson & Schunn, 2000; Pavlik & Anderson, 2006; Lindsey, et al., ICCM 2009; van Rijn, et al., ICCM 2009)*

- Validate model implementations and analysis tools using human performance data from *as broad a range of contexts* as possible

17

Predictive Performance Equation

S = scaling parameter

raised to *-d*, the decay rate

T = time since learning

$$Performance = S \cdot \left(\frac{\sum lag}{\sum P} \cdot \frac{P_i}{T_i} \cdot \frac{\sum_i^j (lag_{\max_{i,j}} - lag_{\min_{i,j}})}{N_i} \right) \cdot N^c \cdot T^{-d}$$

Stability Term: Experience amassed as a function of training distribution and time passed – captures the spacing effect

N = known amount of practice

raised to *c*, the learning rate

18

335

The Spacing Effect

Scenario 1:
Well-Spaced, Distributed Training Regimen

Scenario 2:
Poorly-Spaced, Massed Training Regimen

Conclusion: Principled spacing of baseline training produces durable retention and reduces the need to retrain or reacquire.

Validation with Data from Psychological Literature
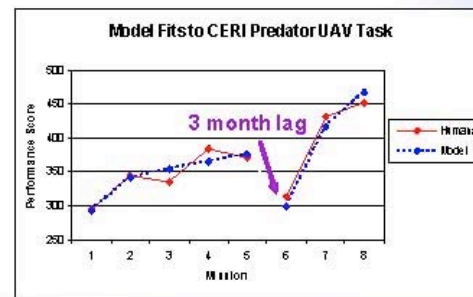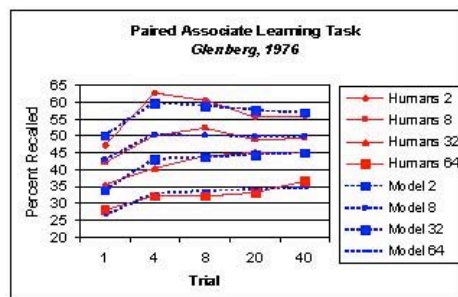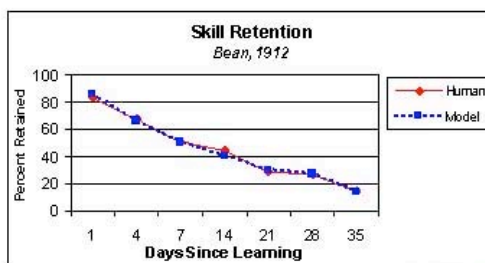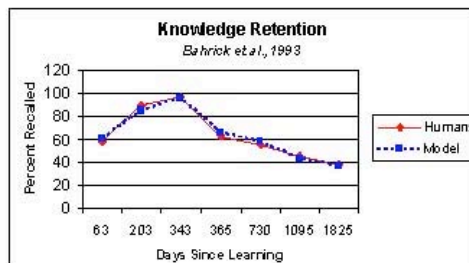
$R^2 = 0.98$

Objective Performance Measurement in the DMO Testbed

F-16 Simulator Data from Vipers 1-4 | Mission Control/Threat System Data

Streaming Data Processed and Time-Stamped in Real Time

Objective Performance Measurements

File Output
Shot Hz Data
Entity Hz Data
Shot Summary
Trial Summary
and more...

Real-Time Displays

Statistical Analyses
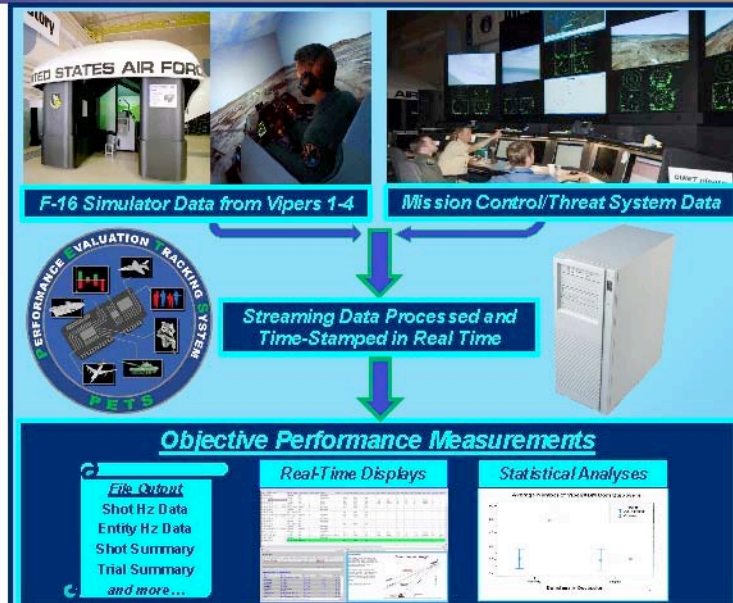
Validation with Data from the DMO Testbed

- Validation effort underway in highly applied/relevant domain
  - Pilot teams composed as 4-ships
  - Complete a week of simulator training research and return either 3 or 6 months later to be reassessed

QUIET please while mission in progress

Validation with Data from the DMO Testbed

-Pilot performance is assessed during a training week
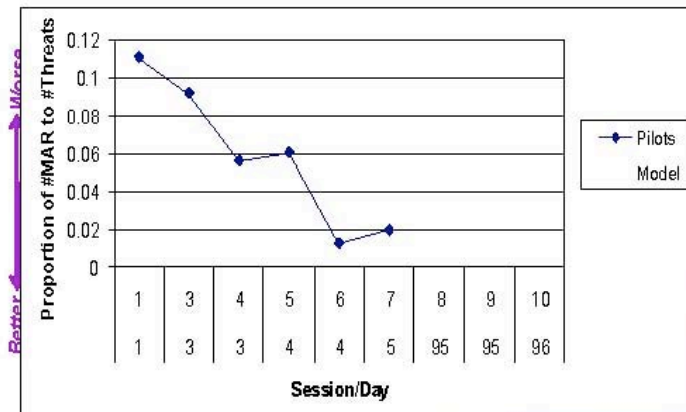
-Identification of meaningful learning variables is key!

Validation with Data from the DMO Testbed

-Model tracks knowledge and skills of learner during initial training – parameters uniquely calibrated at this time
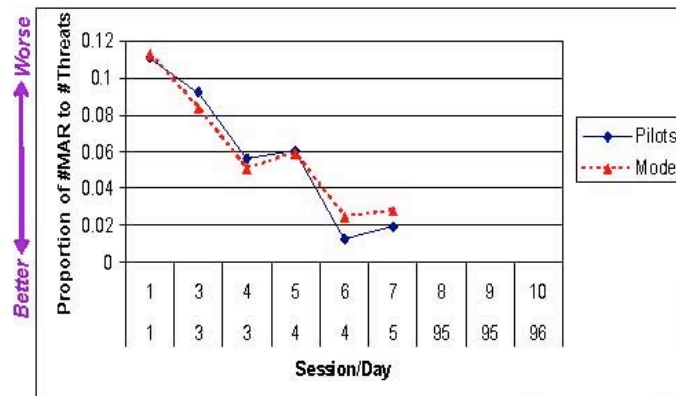
Validation with Data from the DMO Testbed

-*Extrapolates mathematical regularities of knowledge and skill changes to use in a predictive fashion*
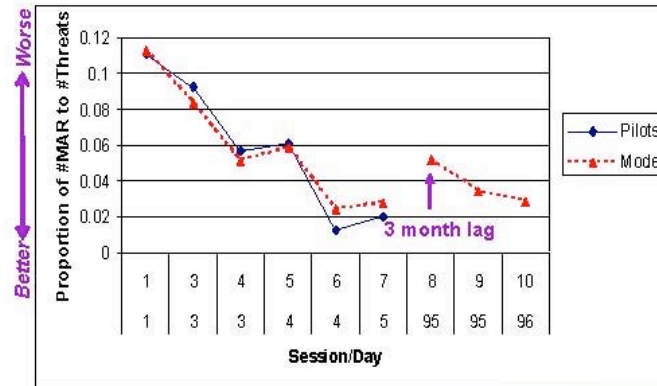
25

Validation with Data from the DMO Testbed

-*Model accurately predicted pilot team performance to a high degree of precision*
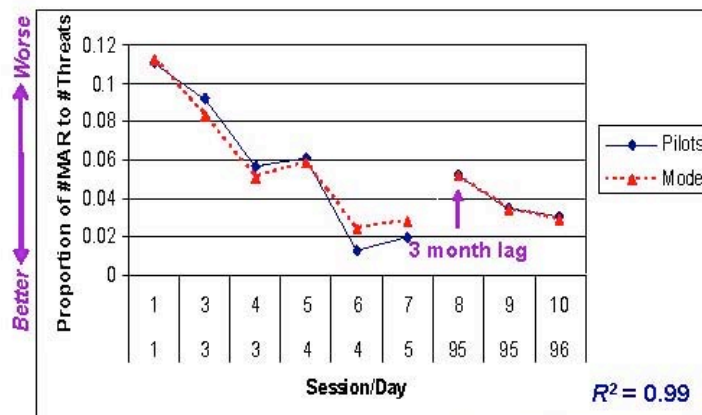
$R^2 = 0.99$

26

339

Outline

I. Historical Background

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IV. Future Directions

27

On the Nature of Applications
- Allen Newell (1990)

"Applications are an important part of the frontier of any theory…"

28

340

Predictive Performance Optimizer Controls & Demonstration

29

Model Sensitivity to the Unique Needs of the Learner

30

Model Sensitivity to the Unique Needs of the Learner

Parameter	Team 115	Team 112
Stability Term	1.46	1.46
Scalar	0.064	0.164
Learning Rate	0.999	0.729
Decay Rate	0.068	0.001

Prescribe Scheduling of Refresher Training to Maintain Readiness

Well-Spaced, Distributed Baseline Training
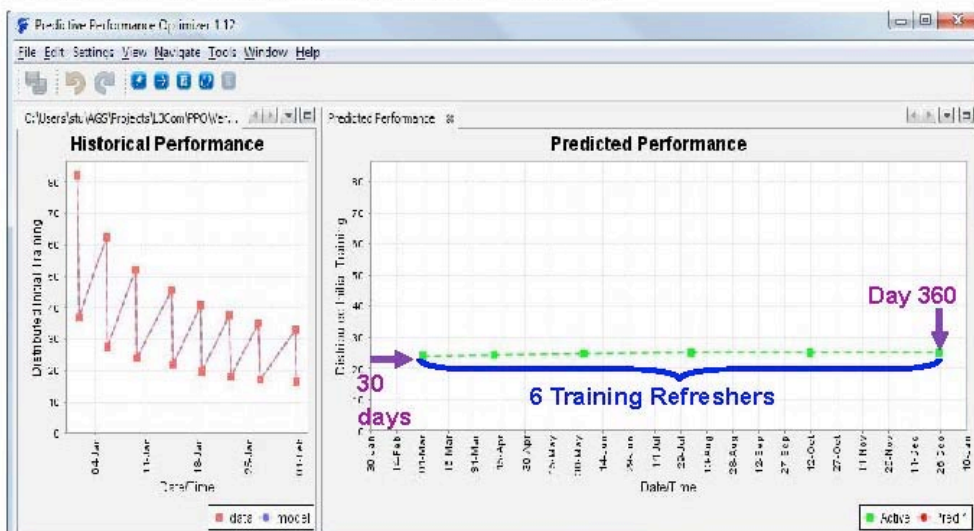
Prescribe Scheduling of Refresher Training to Maintain Readiness

Poorly-Spaced, Massed Baseline Training
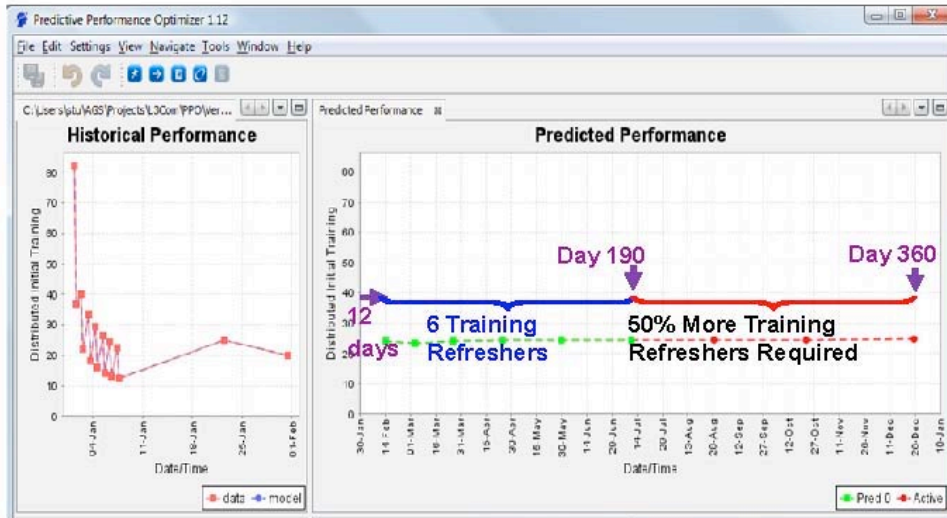
Exploring Predicted Performance Implications

Predictive capability can help determine which future training regimen would best achieve training goals
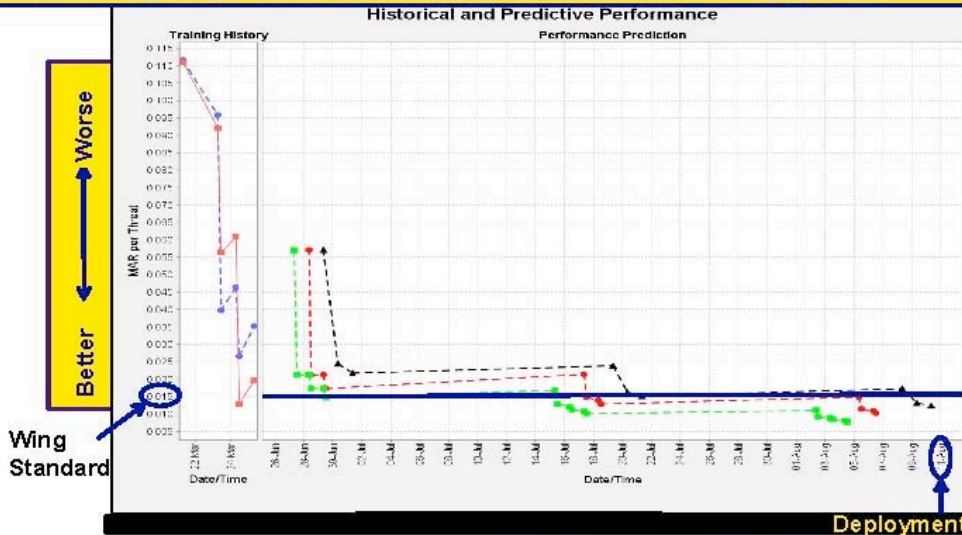
Outline

I. Historical Background

II. Approach and Validation

III. Predictive Performance Optimizer

IV. **Future Directions**

Looking Ahead...

- *Validation in the Field: AETC and Live-Fly Training Contexts*

- *Confidence Intervals and Mission Risk*

- *Neurobiology of learning and forgetting*

Thank You!
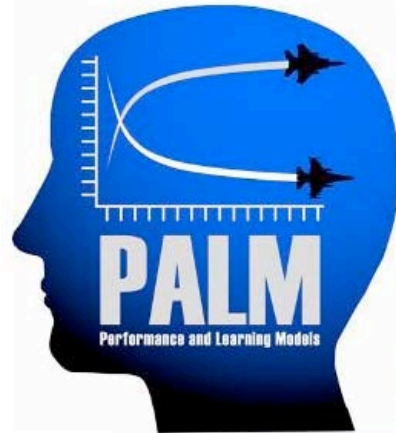
Dr. Kevin Gluck
Kevin.gluck@mesa.afmc.af.mil
(480) 988-6561 x677

Acceleration & Retention Issues: ISR Example

Lt Col Gina Hilger
Chief, ISR Requirements & Ops Div
US Air Forces Central, Shaw AFB

Overall Classification of this Briefing: UNCLASSIFIED

Overview

- **Career Path Broadening**

- **Reintegration Challenges**

- **Thoughts on Ways Ahead**

Career Path Broadening
External & Internal

- **Career broadening encouraged in Air Force (external)**
  - Broader exposure to different careers/functions/levels designed to develop better senior ldrs capable of integrating complex missions
  - Often a stratifier for promotion
  - Professional military education & higher degrees a must
  - Many positions are not affiliated w/ a career field, but must be filled (air attache, PME instructor, legislative liason, ROTC/CC)
- **New intelligence career field guidance (internal)**
  - 3 x areas of core expertise for all intel officers (analysis, global ISR operations, effects-based ISR planning)
  - 6 x professional competencies (analysis, foreign area expertise, global ISR enterprise, targeting, AOC ops, programming/acquisition)
  - Consecutive assignments in same competency by exception only
  - Should have at least two different jobs during one assignment as well
  - Broadening within the intel career field is intentional

Reintegration Challenges
(1 of 2)

- **Difficult to stay in tune w/ primary career field during broadening**
  - Broadening jobs are just as time consuming as career field positions
  - Current supervisors demand your full attention on task at hand
  - Facilities/systems access often not available to keep in touch (eg, classified material/buildings/badges, need-to-know clearance)
- **Reintegration as a CGO may not be as difficult if return to same competency (not guaranteed)**
- **Reintegration as an FGO much more challenging**
  - Greater supervisory/leadership responsibilities
  - Limited time to focus on learning / reintegrating (high ops tempo)
  - Slave to the "task master;" always putting out fires
  - Multi-tasking is the norm; no large chunks of time to study at work
  - Burden of reintegrating often on the individual; no deliberate program
  - Fewer FGOs in unit – can't afford to lose one for lengthy trng courses
  - Tendency to seek & to be given tasks that fall within prior expertise

Reintegration Challenges
(2 of 2)

- **"No one" knows you anymore when you return to field**
    - Previous mentors no longer available (many retired); need new ones
    - Previous social network at AO-level no longer intact
    - Must often re-build strong reputation again within career field
- **Managing subordinate & other expectations**
    - Harder to ask for help (particularly when return as an FGO)
    - Subordinates expect you to be an "expert" based on time in service
    - Joint and component counterparts also expect you to be an "expert"
- **Sense of frustration & initial loss of confidence**
    - Competitively selected for career broadening opportunities, but may negatively impact career progression within own field
    - Some thoughts of "getting out" & starting 2nd career early
- **Programmatic challenges**
    - Too few slots at training courses; often must be deploying to attend

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Thoughts on Ways Ahead
(1 of 2)

- **"Just in time" training courses in intel do exist**
    - IFTUs (space, AOC, platform, DCGS, AFSOC, targeting)
    - Need to increase number of slots
- **Reintegration must be more deliberate, at least in intel field**
    - Need mechanism to flag those officers returning to the field
    - Add training line remarks to billets for returnees
    - Schedule course attendance *enroute* to next job to ensure it happens
    - Treat returnees similar to those shifting intel core competencies
    - Developmental Team (DT) vectors can address expertise acquisition
- **Intelligence Master Skills Course (IMSC)**
    - Good for "breadth;" consider sending FGO returnees back to IMSC
- **Computer Based Training (CBTs)**
    - Good for exposure, but not deep comprehension
    - Time available a factor

Thoughts on Ways Ahead
(2 of 2)

- **Deployments build expertise quickly; learning accelerated**
  - Fewer distractions; long periods of time to focus
  - Hands-on application of knowledge aids expertise retention
  - Need high fidelity training courses that replicate oper environment
- **Reintegration must occur primarily during duty hours**
  - Off-duty time needed to recover from high deployment rate (1:1 dwell)
  - Retention factor – "burn out" on the horizon for many
- **Tailor training programs to individual's preferred learning style**
- **Voluntary "Warrant Officer" program**
  - Observation: Majority of intel Subject Matter Experts (SMEs) are civilians/ contractors (more time to study intelligence literature & develop intuition)
  - Two tracks: One for leadership/command, one for subject expertise
- **Need to study what level of expertise is required to *lead* a team of experts vice being the expert yourself (managerial expertise)**

Questions?

Overall Classification of this Briefing: **UNCLASSIFIED**

Accelerated Learning and Facilitated Retention

Paul J. Feltovich
Robert R. Hoffman
Institute for Human &Machine Cognition

Steve Fiore
University of Central Florida

Gary Klein
Klein Associates Division of ARA

Outline

1. Issues
2. Empirical Base (academe and "real world")
3. Theories & Hypotheses
4. Phenomena of Training & Transfer
5. Conclusions & Challenges
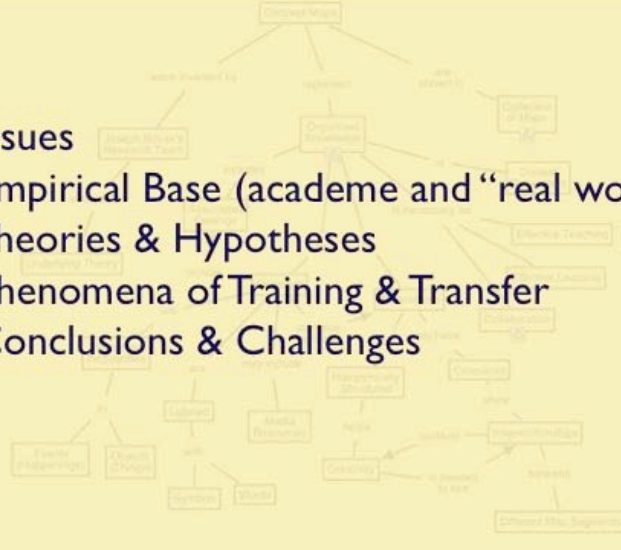
1. Issues

Workforce
    Grey Tsunami

Continuity of knowledge and skill
    Army TRADOC "Continuity Files"

Moving Target Issues
    Continual change in macrocognitive work and its technologie

DoD domains in particular
    Needs for adaptability, flexibility, transfer

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1. Issues

"The military has a training problem"
(Chatham, 2009)

• Traditional versus "SSTR" operations

  (Stability, Security, Transition, Reconstruction, DoD, 2005)

• "Today's missions…require that we also train each soldier
to be a little bit of a linguist, anthropologist, city manager,
arbitrator, negotiator, engineer, contact specialist,
ambassador, and consummate bureaucrat… " (Chatham, 2009)

"New" Directions in Expertise Studies

"The chapters (in this book) make it clear that the field has built upon, yet gone beyond, the classic research studies that compared expert and novice performance. The emphasis has turned to the *development* of expertise…" (Bransford & Schwartz, 2009).
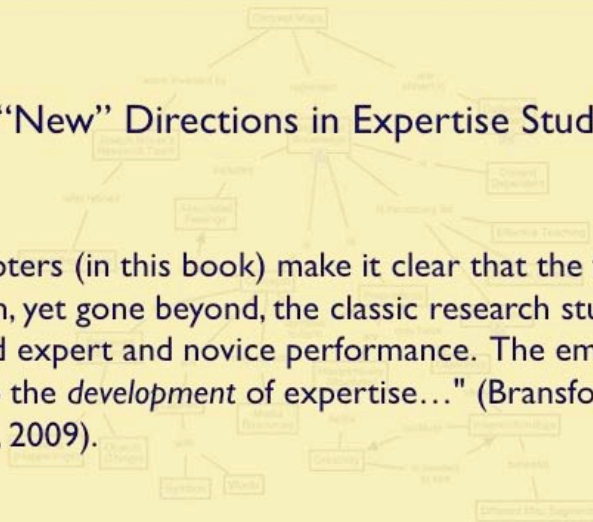
Accentuated Needs

- Adaptability
- Flexibility
- Transfer
- Learning
- Continuity - Capability Preservation for Sharing

2. Empirical Base: Academic Studies

Psychology of Learning
　　　Studies of long-term retention
　　　Studies of transfer

Proficiency Scaling
　　　10,000 hours is misleading/misguided
　　　Initiate-apprentice-journeyman levels, in particular
　　　Accelerate across the apprentice-journeyman gap

Longitudinal perspective
　　　Needs for adaptability, flexibility, transfer

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2. Empirical Base: Academic Studies

Deliberate Practice

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

Transfer Appropriate Processing

Morris, C.D., Bransford, J.D., & Franks, J.J. (1977). Levels of processing versus transfer-appropriate processing. *Journal of Verbal Learning and Verbal Behavior, 16,* 519-533.

Adaptive Expertise

Hatano, G. and K. Inagaki (1986). "Two courses of expertise." *Child Development and Education in Japan*, pp. 262-272.

Training Across the Proficiency Scale

Trainees learn more from successes because they need help figuring out what to do.

Experienced people learn more from failures because they have already mastered the routines and are in a position to make use of the information found in errors.

Hence, the value of Decision Making Exercises

Successful Cases of Acceleration

- Top Gun
- National Training Center (NTC)
- The "first training revolution"
- "Engagement Simulations" (Chatham)

2. Empirical Base: the "Real World"

Viet Nam: Air-to-Air Ratios: "Top Gun"

- Pre Top Gun: Navy 2:1 Air Force 2:1

- Navy Instituted "Top Gun," Navy Fighter Weapons School. Air Force did not.

- Post Top Gun: Navy 12.5:1 Air Force ~2:1 (Air Force actually dipped a bit)

2. Empirical Base: the "Real World"

Field Battle: National Training Center ("NTC"): Increased Success Rates, Post Training

- Light infantry platoons: 30:1
- Combined arms teams: 15:1
- Regiments/Brigades   5:1

(Duration: 3-4 Weeks at NTC)

2. Empirical Base: the "Real World"

Characteristics of Successful Programs

- Independent, representative, and superior opposing ("red") force (translates, more generally to "tough cases")
- Ability to measure what happened
- As high fidelity *as needed*
- ARR: After Action Review:

  Objective, detailed feedback

  Situation awareness, decision processes, state of mind

  Participation at all levels, and as real functional units

  Self Assessment in addition to external
- Tailoring to the learner (individual and/or group), "customized"

356

Cognitive Flexibility Theory

Spiro, R. J., Feltovich, P. J., Jacobson, M. J. and Coulson, R. L. (1992). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. M. Duffy and D. H. Johassen (Es.), *Constructivism and the technology of instruction: A conversation (pp. 65-75)*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cognitive Transformation Theory

Klein, G. and Baxter, H. C. (2009). Cognitive Transformation Theory: Contrasting Cognitive and Behavioral Learning. In *The PSI Handbook of Virtual Environments for Training and Education: Developments for the Military and Beyond, Vol. I: Learning, Requirements, and Metrics* (pp. 50–65). Santa Barbara, CA: Praeger Security International.

Common Elements Theory

Thorndike, E. L. (1921). *Educational psychology, Volume II: The psychology of learning.* New York: Columbia University Teacher's College.

Common Elements Theory

Learning and transfer have to do with the strength of stimulus-response bonds. These, ultimately, can be understood as being neuronal connections; the bonds are "in neurones" (p. 354). Transfer is when the strengthening of one S-R bond also strengthens some other S-R bond.

		Bond B (Transfer Task)	
		Strengthened	Weakened
Bond A (Original Task)	Strengethened	"Positive similar change," or facilitation	Positive opposite change," or inhibition
	Weakened	"Negative opposite change"	"Negative similar change"

Common Elements Theory

"... a change in one function alters any other only insofar as the two functions have as factors identical elements... the change is simply the necessary result upon the second function of the alteration of those of its factors which were elements of the first function, and so were altered by its training. To take a concrete example, improvement in addition will alter one's ability in multiplication because addition is absolutely identical with a part of multiplication, and because certain other processes, e.g., eye movements and the inhibition of all save arithmetical impulses, are in part common to the two functions" (pp. 358-359).

"… in a more or less mysterious way, learning to do one thing well will make one do better, things that in concrete appearance have absolutely no community with it."

Thorndike, 1921, p. 364.

We may not need to make more experts,
but we do need to study them
so that we can learn from them

- Deliberative preparation
- Anticipation of difficulties and constraints shapes the practice environment
- Constant practice at performance self-diagnosis.

Eccles, D. W. and Ward, P. and Woodman, T. (2009). Competition-specific preparation and expert performance. *Psychology of Sport and Exercise, 10*, 96-107

Paradoxical Effects

"So a man trained for an hour on a typewriter of standard keyboard might, after a second hour of practice, with the keys being changed... do worse than at the beginning; but if he practiced an hour daily on each sort of machine he would not fall back to his initial score for long, would soon come to be able to turn from one to the other system of bonds at the mere sight of the machine, and would probably find that 20 hours of the two alternative systems gave greater ability at either than ten hours of practice at each alone would have given" (pp. 356-357).

Paradoxical Effects

- The easy, fast way may not get you there
- Short results versus long term retention and transfer
- Some things that make learning harder also make it better
- Bjork's "desirable difficulties" in learning

Paradoxical Situations

- The paradox of Deliberate Practice – the more limited the focus, the better the training but the less you can cover.

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4. Phenomena of Training & Transfer

Mistakes and Near Misses Can be Good

- Deliberate practice-- always "stretching"

- Olympic skaters fall down in practice

- After Action Reviews,
    - Morbidity and Mortality Conferences,
    - "Think-Like-a-Commander,"
    - High Reliability Organizations,
    - Tough Cases…

5. Conclusions and Challenges

When the notion of "task" no longer applies. . . .

Goals morph
Tools morph
Emerging surprises
Constant multitasking

Cyberwar
UxV operation

---

5. Conclusions and Challenges

Assumptions about the concept of "task" in ALL theories and
hypotheses about transfer:

Isolable
Fixed, stable "elements"
Stable goals
Proceduralizable

Moving Target Problems

Some jobs, such as piloting, involve constant and intense multitasking.
Focusing serially on the achievement of goals can even be dangerous.
The worker must do parallel attention.

Retention and transfer training, by tradition, have focused on the
idea of isolated, individual skills, rather than skill at multitasking per se.

5. Conclusions and Challenges

Measurement Issues

HEAT measurement (hits, errors, accuracy, time)
works form some jobs/tasks, but not for many others
System-level measurement.
Moving Target Problems
The problem of "representative tasks"
The problem(s) of control.
Measurement at higher-levels of proficiency (journeyman, expert)
where performance is near ceiling

5. Conclusions

Current propositions concerning training

INITIATE
Experiential learning
The trainee first experiences learning content through hands-on practice and then reflects upon that experience while trying to abstract key ideas.
Can rely on simulation systems.
Learning from Errors
Modifying the scenarios within the simulation such that they emphasize common misconceptions, that is, correct reductive or flawed mental models.
Problem-based Learning
Scenarios are populated with more challenging content.

APPRENTICE
Situated Learning and Cognitive Flexibility
Actions and decisions are practiced in the context of the operational environment, and when warranted, the learner is guided in his/her own performance. This could be implemented with simulation-based environments or practiced in the field.

5. Conclusions

Current propositions concerning training
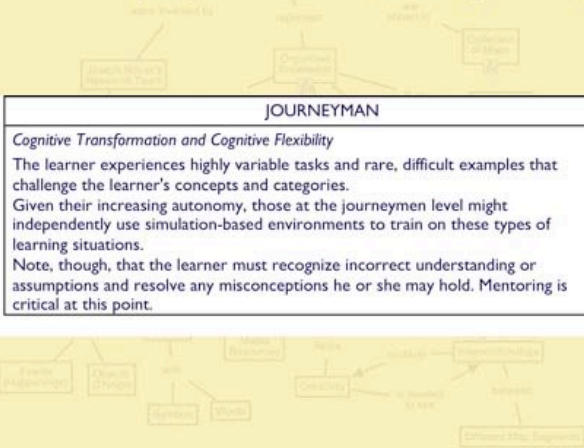
JOURNEYMAN
Cognitive Transformation and Cognitive Flexibility
The learner experiences highly variable tasks and rare, difficult examples that challenge the learner's concepts and categories.
Given their increasing autonomy, those at the journeymen level might independently use simulation-based environments to train on these types of learning situations.
Note, though, that the learner must recognize incorrect understanding or assumptions and resolve any misconceptions he or she may hold. Mentoring is critical at this point.

5. Conclusions

✪ You need KE for continuity

KE ➔ Case Corpus

Tough Case corpus enables "time compression"

✪ You need to cope with the Moving Target

Invert the Common Elements Theory

Hiatus (maintenance) training focuses on what is *different* or changing

Quick relevant observations with situated assessment

R. Hubal

RTI International

09-10 October 2009

Background for one study

- Many inner-city adolescents are at risk during social situations that require:
  - Emotional control.
  - Conflict resolution through negotiation, seeking information, expressing preferences.
  - Adverse consequences include violence, school suspension, criminal activity.
- Training on these skills is well studied, but...
- Assessment is unsatisfactory:
  - Want to assess adolescent's learning before he's "on the street".
  - Existing methods use surveys or text-based cases, not "assessment-by-doing".

Solution

- Vignette storylines designed to target skills:
  - That is, competencies – engaging in negotiation, maintaining emotional control and being non-provocative, seeking information.
- Language models designed to interpret participant input as reflecting one or more social skill.
- Behavior models designed so that the virtual character attempts different strategies to require participants to demonstrate skills.
- Methods devised to measure participant engagement.
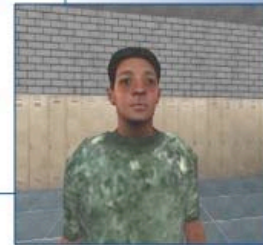
Methods

- Procedure:
  - Participant given pre-test set of vignettes.
    - Wizard-of-Oz methodology.
    - Monitor how participants handle vignettes designed to elicit risky behavior.
  - Participant given standard text-based assessments.
  - Participant shown PACT video in presence of facilitator.
  - After up to 6 month delay, participant given post-test set of vignettes (again WoZ).
  - Behavioral reports, teacher ratings, self-reports collected.

4

Methods, continued

- **Measures:**
  - ◆ Engagement with vignettes.
  - ◆ Body language.
  - ◆ Verbalizations.
  - ◆ Number of conversational turns.
  - ◆ Response time.
  - ◆ Outcome:
    - – Positive outcome is to decline or back away.
    - – Negative outcome is to agree or escalate confrontation.

Results

- **Scoring procedures used during pre/post test with vignettes identify:**
  - ◆ Level of emotional control.
  - ◆ Interpersonal communication skills.
  - ◆ Analysis against established measures provides some support for construct and criterion validity.
- **Nearly all queried participants stated their virtual decision mirrored what would be their real-life decision.**
- **Note: acceptability / usability not different among groups.**

- **Participants agree to help/go along with/escalate confrontation with the synthetic character one-third to half of time.**
- **Simulation effective in differentiating:**
  - ◆ Adolescents with clinical Conduct Disorder.
  - ◆ Adolescents who had participated in live training sessions on key skills.
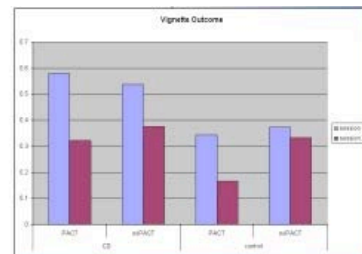
Observations

- **Design of vignettes:**
  - ◆ Set of vignettes needs to encompass competencies.
    - – Thus, need to have theory defining competencies.
  - ◆ Need to be realistic (engaging).
- **"Representative tasks":**
  - ◆ Need to be realistic (relevant).
  - ◆ Consider context – language, clothing, gestures.
    - – The experience in location A should equate to the experience in location B.
  - ◆ Describe research as about competent performance, not "expertise".
- **More in one-page concept paper ...**
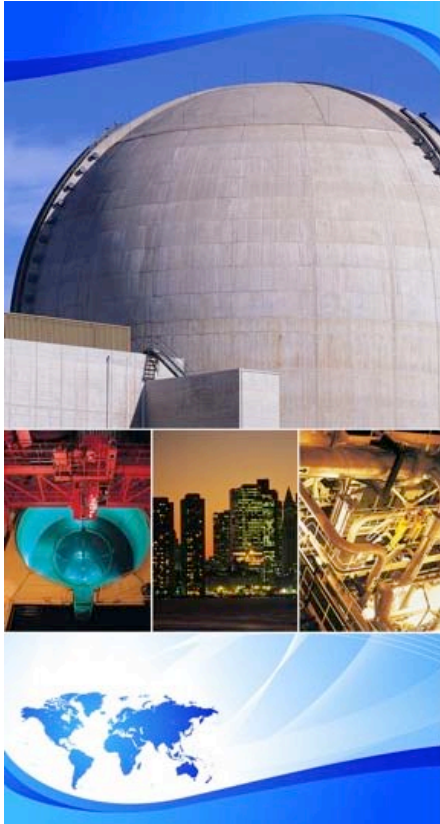
Electric Utility Super-Experts

Acceleration and Retention issues

David Ziebell
dziebell@epri.com

Goals for this presentation…

- A little about EPRI and EPRI's work on a particular subset of knowledge management: Capturing tacit knowledge
  - Evolution toward expert knowledge and experts
- Industry examples
- A speculation

2

369
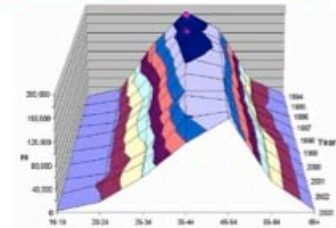
Our History…

- Founded by and for the electricity industry in 1973

- Independent, nonprofit center for public interest energy and environmental research

- **Collaborative** resource for the electricity sector

- Major offices in Palo Alto, CA; Charlotte, NC; Knoxville, TN
  - Laboratories in Knoxville, Charlotte and Lenox, MA

Chauncey Starr
EPRI Founder

3

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Our Members…

- 450+ participants in more than 40 countries

- EPRI members generate more than 90% of the electricity in the United States

- International funding of more than 15% of EPRI's research, development and demonstrations

- Programs funded by more than 1,000 energy organizations

4

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Our Role…

Help Move Technologies to the Commercialization Stage…
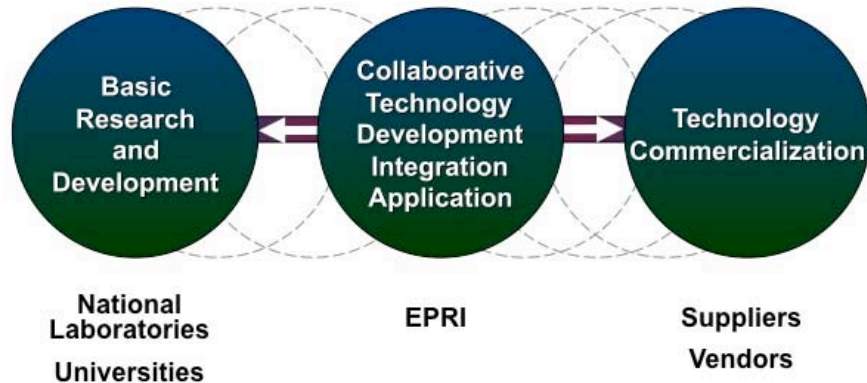
Basic Research and Development

Collaborative Technology Development Integration Application

Technology Commercialization

National Laboratories Universities

EPRI

Suppliers Vendors

Technology Accelerator!

5

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Portfolio Spans the Entire Electricity Sector

Generation	Nuclear Power	Power Delivery & Utilization	Environment
• Advanced Coal Plants, Carbon Capture and Storage	• Advanced Nuclear Technology	• Transmission Lines and Substations	• Air Quality
• Combustion Turbines	• Chemistry, Low-Level Waste and Radiation Management	• Grid Operations and Planning	• Global Climate Change
• Environmental Controls	• Equipment Reliability	• Distribution	• Land and Groundwater
• Generation Planning	• Fuel Reliability	• Energy Utilization	• Occupational Health and Safety
• Major Component Reliability	• Instrumentation and Control	• Cross Cutting Technologies	• T&D Environmental Issues
• Operations and Maintenance	• Material Degradation/Aging		• Water and Ecosystems
• Renewables	• Nondestructive Evaluation and Material Characterization		
	• Risk and Safety Management		
	• Used Fuel and High-Level Waste Management		

6

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EPRI Research Results and Methods

2000	1004658	Capturing Undocumented Worker-Job-Knowledge: Overview and 2000 Status Report
2002	1004663	Guidelines for capturing valuable undocumented knowledge from energy industry personnel
2002	1002896	Capturing and using high-value undocumented knowledge in the nuclear industry—guidelines and methods.
2004	1009581	Real-Time Expert Knowledge Acquisition & Transfer
2008	1016710	Accelerating the Achievement of Mission-Critical Expertise

Identify Experts from whom knowledge will be captured → **Develop Plan** to capture expertise and make it available when needed → **Implement Plan** and develop Knowledge Modules (KMs)

7

Actual challenges met by EPRI's method…

- Transmission System Protection Expert is retiring and he's the only person who can quickly and reliably diagnose weird protection system operations
- Fractionated semi-computerized billing system still in service but the guru is moving on
- Chief System Operator who has held the ECC together during several corporate transitions, including incorporating 1995 OSHA requirements (for violations of same, industry people have been jailed) has retired
- Young underground station operators just don't seem to "get it" about how to respond to common events, and the operating engineer (smart, two years with company) has taken over for the promoted/transferred prior expert

8

More examples …

- Senior VP special projects – called for disasters large and small
- Chief operator of natural gas liquification plant nearing retirement just as system re-design is needed
- Engineering Manager facing high turnover in an aging system facing a growth spurt – long range planning process needs

9

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Insight: A possible gap in traditional methods

Three Kinds of Expertise Needed

Leadership ➡ Succession Planning

Key Technical Wisdom ➡ Wait while experience grows?

Productive Workforce ➡ Workforce Planning, Training, Information Technology, Performance Tools

Traditional methods address two

10

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EPRI's tacit knowledge method works 2 ways

- Middle-of-the-bell-curve Undocumented Knowledge Capture
  - Often can be captured efficiently and rather easily
  - Can (should) be made widely available via training or digital tools: *Transfer* is well understood, systematic

- High-end Technical Wisdom Capture
  - Often requires much effort to capture
  - Successful transfer to a few specified individuals is proven, but not yet systematic
  - *The value is at the fringes of the discipline – where resilience lives*

11

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Example "Big Picture" for mass consumption

12

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Example – LNG Operations
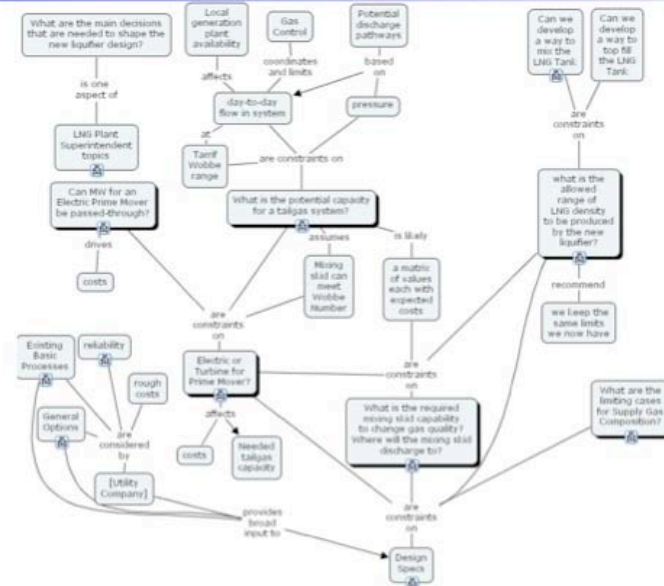
13

Example "Expert Thought Process" Transfer

- **Captured tacit knowledge organized**
- **Process is a basis for expert judgment**
  - **Not simply facts, but *transformed* knowledge**
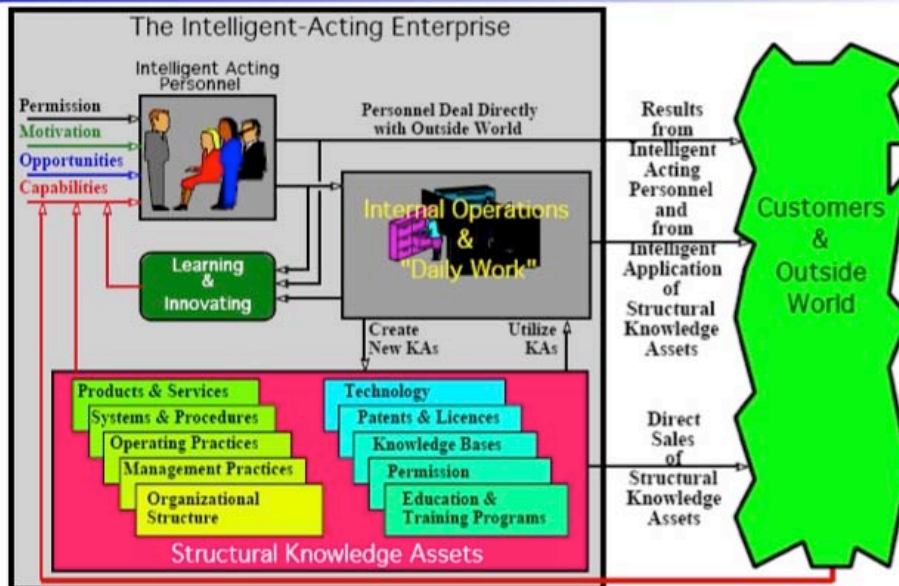 - **Demonstrates the adaptivity we seek in our experts**
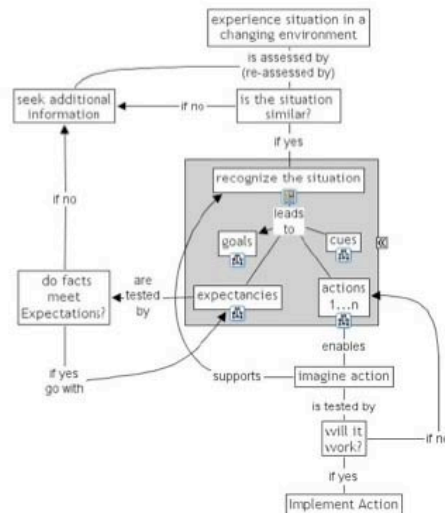
14

375

Where are the "Agents" and what can they do?

The Intelligent-Acting Enterprise

From "Knowledge Management: An Emerging Discipline Rooted in a Long History" Karl M. Wiig

15

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A Speculation

- Agents are of two kinds
  - the knowledge worker, middle of the bell curve producer that does repetitive pre-planned work in a quasi-stable system. Some knowledge workers are experts who are allowed to improve the efficiency of the pre-planned work within the quasi-stable system
  - The super expert, having agency/authority (granted or tacit) to change the quasi-stable system and it's relation to the outside world.
    - Institutions are dependent on these super-experts for resiliency but don't often explicitly act like this.
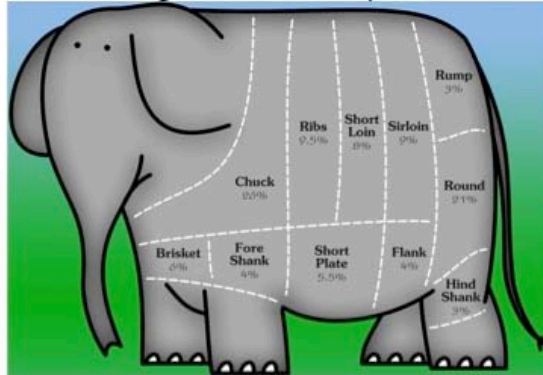
16

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Potential Barriers in Utility Space

- Non-standard problems – chaotic or merely complex?
- Difficult problems rare – 25-35 years to see enough?
- Complexity plus longevity (of the technology)
- Biggest problems occur at the fringes of a discipline – the fog of society

17

Together...Shaping the Future of Electricity

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Image from *NASA Visible Earth*

377