Learning and Performance Across Disciplines: An Epilogue for Moving Multidisciplinary Research Toward an Interdisciplinary Science of Expertise

Stephen M. Fiore a, Robert R. Hoffman b, Eduardo Salas a
a University of Central Florida, Orlando, Florida
b Institute for Human and Machine Cognition, Pensacola, Florida

Online Publication Date: 01 January 2008
To link to this article: DOI: 10.1080/08995600701804939

URL: http://dx.doi.org/10.1080/08995600701804939

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article maybe used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Learning and Performance Across Disciplines: An Epilogue for Moving Multidisciplinary Research Toward an Interdisciplinary Science of Expertise

Stephen M. Fiore
University of Central Florida, Orlando, Florida

Robert R. Hoffman
Institute for Human and Machine Cognition, Pensacola, Florida

Eduardo Salas
University of Central Florida, Orlando, Florida

We conclude this special issue, not with a summary, but with a forward look. We consider a number of issues related to those presented in this special issue, with the goal of suggesting how we might build upon the tremendous body of work in sports research. We begin with a discussion of the issues surrounding what it means to create interdisciplinarity in a domain of inquiry. Then, we briefly discuss potential ways of adopting methods and concepts from the contributing disciplines. Following this, we discuss notions of self-improvement in learning and integrate this with a continuum of expertise development that is appropriate to the context of the contributions to this special issue. We conclude with a discussion of a set of research directions for interdisciplinary studies of the development of expertise.

At its most general level, expertise can be viewed as the skillful execution of knowledge and skill to achieve effective action. Contributing to this special issue are researchers who are experts themselves in the study of domains of human activity that manifest varied forms of superior performance. The goal with this spe-
cial issue was to begin what we believe can be a productive dialogue and collaboration between the military and sports sciences. We have sought to facilitate a cross-pollination of views and approaches that will provide the potential for discrete gains in our understanding of human performance in general, and expertise, in particular.

Thus, we conclude this special issue, not with a summary, but with a forward look. In order for research in expertise to integrate theories and methods from the various pertinent disciplines, not only must the ideas put forth in this special issue be explored in the context of collaborations across disciplines, but we must also consider the ways in which collaboration can be realized. In service of this, we identify what we see as areas of research that might act as a form of collaboration scaffolding; that is, areas of inquiry where the ideas presented in this special issue can be brought together in support of research on enhancing learning and performance. First we discuss some of the issues surrounding what it means to create interdisciplinarity across somewhat disparate domains. Then we briefly discuss potential ways to adopt concepts and methods from varied disciplines. Following this we discuss notions of self-improvement in learning and then discuss ideas pertaining to a continuum of expertise. We conclude by presenting a set of research directions devised to support training for the development of expertise.

ON INTERDISCIPLINARY RESEARCH IN EXPERTISE STUDIES

Science is about understanding a concept or concepts, not only in depth, but also in general. Indeed, the bane of researchers in countless domains is the continuing question of “yes, but does it generalize to…” Nonetheless, science recognizes this responsibility to seek out and identify the regularities across concepts when they exist. This type of cross-domain generalization is not a new concept to the field of expertise studies. Indeed, expertise research is perhaps one of the rare fields where issues of generalizability have been salient as long as the field has existed, across a myriad of disciplines. In studies ranging from burglary to basketball, from computer programming to karate, from electronics to chess, research has consistently demonstrated similar performance patterns where, for example, experience is an aid in that it allows one to see the greater relation among meaningfully presented environmental cues (see Hoffman, 1992).

Nonetheless, despite such findings and such cross-domain generalizations, as this special issue shows, there is still much to profit from a more systematic integration of ideas and improved collaboration across disciplines. With this we are reaching not for multidisciplinarity in research, but beyond that, for the development of an interdisciplinary science of expertise. Multidisciplinary research, although involving a coordinated effort bringing together several disciplines in service of some common
goal, relies upon complementary contributions. Interdisciplinarity demands more than just complementarity. Following distinctions made in science policy on developing interdisciplinarity, we argue that, if research on expertise is to become a type of science of expertise, there is a requirement for a form of collaboration that leads to the design of new types of complex empirical approaches along with integrated analyses combining methods and concepts from participating disciplines (e.g., Pellmar & Eisenberg 2000; Klein, 1996). Specifically, an interdisciplinary science of expertise must integrate a set of disciplines so as to create not only a unified outcome but also something new, a new language, a new way of understanding (Barthes, 1989), and do so such that it is possible for a new discipline to evolve over time (NAS, Committee on Facilitating Interdisciplinary Research, 2005).

What this suggests is that there needs to be increased communication and collaboration across disciplines in service of interdisciplinarity. Indeed, this is a prime example illustrating why interdisciplinarity is no longer a buzzword but a 21st-century necessity requiring more coordinated and even large-scale scientific efforts that cut across disciplines. What is critical to realize in this regard is that “the way in which our universities have divided up the sciences does not reflect the way in which nature has divided up its problems” (Salzinger, 2003, p. 3). The academic model of disciplinary specialization, while leading to in-depth knowledge, can sometimes come at a cost of breadth. Thus, although there certainly is much to be gained from academic specialization, it can sometimes come with the cost of disciplinary isolation. As such, the academic communities must be mindful of the need to place increased emphasis on collaboration across disciplines and try to identify a feasible combination of breadth and depth of knowledge.

The rationale for this special issue was to envision such collaborations in the service of a long-term goal of an interdisciplinary science of expertise—one only possible when theories and methods from multiple disciplines are brought together, integrated, and transformed as a result of the integration. In this context, we turn next to a discussion of collaboration between the military and sports sciences. We have framed this around the language of science policy—that of low-risk versus high-risk research in the sense of their producing usable outcomes in service of creating interdisciplinary theories. Funding agencies have long characterized scientific endeavors along some form of risk-related rating with the notion being that, for example, funding low-risk research is likely, particularly in the short-term, to create usable knowledge. Specifically, risk is typically considered in the context of research policy decision-making and is associated with notions of usable outcomes and of time (Fiore & Salas, 2007). Although a somewhat superficial treatment of a complicated issue, we present this to convey an understanding that both fundamental and high-risk research requires a long-term investment and may not always produce usable outcomes (for a more refined set of such distinctions, see Hoffman & Deffenbacher, 1993). Specifically, risk is strongly associated with basic science given that such research often has associated with it a low likelihood of producing
significant gains in usable knowledge in the short term. As such, we use this terminology to point the community toward areas of research that vary in risk but that all could produce significant gains, not only for the military, but also in illustrating an interdisciplinary science of expertise.

ADOPTING TOOLS AND METHODS ACROSS DISCIPLINES

As noted at the beginning of this special issue, where we provided a matrix listing factors engaged during the execution of skilled performance and showed them in the context of varied domains, it is also possible to consider the rich array of methods evolving out of these disciplines, including the techniques discussed in this special issue. From this, an additional dimension for a matrix may be useful. In particular, crossing domains, processes, and methods, one could call attention to those methods that are appropriate (or not appropriate) to particular domains along with currently untested approaches. In this way, one could identify the areas needing research to chart where methodological gains would be necessary or possible. Researchers well versed in methods from either the military or sports sciences could collaborate to pursue testing new methods and applying them in the study of a broader array of theoretical issues. For example, the utility of anticipation training from perceptual learning research in tennis, as discussed in this special issue, can be explored in military tasks requiring comprehension of dynamic and rapidly presented input.

This form of methodology-focused collaboration might leverage the skills of a spectrum of expertise researchers and be pursued with only a modicum of risk associated with it (e.g., risk that the newly applied method does not prove to be useful). In particular, this is medium risk because pursuing the use of methods from differing disciplines might have associated with them a considerable learning curve. Developing and relying upon multidisciplinary teams might allow a collaboration of researchers to contract the learning curves and rapidly move forward via utilization of the skill of others well versed in their intricacies. Granted, collaboration across disciplines will always have learning curves associated with it (e.g., communication problems derived from differing terminology), but the costs of those burdens may be outweighed by the potential benefits. For example, researchers in both sports and the military attempt to understand perception in dynamic environments. In this instance, those well versed in eye-tracking in sports might collaborate with those studying military operations in urban terrains. Here, complementarity of research area, that is, visual perception, can be supported through adoption of method; that is, eye-tracking. As such, experts in eye-tracking can either educate collaborators about what is and is not feasible with eye-tracking or support them in what could very well be innovative uses of such methods. Addi-
tionally, researchers in both sports and the military have explored team coordination. With this example, military researchers who have developed training programs for shared mental model development could collaborate with those working with sports teams to ascertain the degree to which such training programs are adaptable to these other areas (see Fiore & Salas, 2006).

In sum, leveraging these and related complementary methods could allow researchers to engage in studies of expertise in ways that have important scientific and practical implications. From this, we increase the likelihood of multidisciplinary methods leading us to theories that transcend the individual disciplines.

We turn next to a discussion of particular areas of inquiry where researchers in the sports and military sciences may be able to pursue the development of new theories of expertise.

**PROFICIENCY AND SELF-IMPROVEMENT**

In this section we discuss the notion of self-improvement in sports—that is, the fact that athletes are constantly practicing at performance self-diagnosis. In this their goals are reductions in error, increases in points, or increases in speed. 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 spend 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 striking similarity to the military’s use of the brief-debrief cycle in which teams engage in reflexive activity in services of improvement (e.g., Cannon-Bowers, Rhodenizer, Salas, & Bowers, 1998; Tannenbaum, Smith-Jentsch, & Behson, 1998; Vashdi, Bamberger, Erez, & Weiss-Meilik, 2007).

What we see here is a similarity in the systematic integration of preparation, execution, and reflection (see Fiore, Johnston, & Van Duyne, 2004; Fiore, Salas, Cuevas, & Bowers, 2003; Smith-Jentsch, Zeisig, Acton, & McPherson, 1998), all implemented over a relatively large span of time (e.g., sometimes up to weeks and months). Both the sports and military sciences, then, have drawn from psychology and education’s long tradition of studying the effects of practice and feedback (e.g., Bjork, 1994, 1999; Novak & Gowin, 1984; Thorndike & Woodworth, 1901; Woodworth, 1938). In so doing, the military and sports sciences have developed their own unique ways to prepare for and/or reflect upon a given training experience. We suggest that collaborative research might examine the degree to which practice methods can be tested across disciplines. This cycle of training can be de-
scribed as pre-, in-, and post-process factors; that is, preparation, execution, and reflection, respectively.

We choose this terminology of preparation, execution, and reflection, as opposed to phrases such as brief-debrief, because it represents a more discipline free way to conceptualize the training cycle. Preparation involve preparatory pretask behaviors 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. Similarly, reflection would include posttask 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; Knerr, Lampton, Martin, Washburn, & Cope, 2002; Tannenbaum et al., 1998). It is important to include not only preparation and reflection (e.g., prebrief and debrief) but also in-process factors, because these all help us parse the training cycle in such a way that more efficacious interventions can be explored. Although we recognize that people are always learning while performing, that is, that learning is continuous and occurs in parallel with other cognitive processes, such as decision-making in the field (e.g., Klein et al., 2003), here we are describing formal training programs where specific content is being delivered over a set period of time.

We view this as a relatively low-risk collaborative venture. In particular, military and sports sciences researchers could coordinate their complementary techniques related to preparation for, execution of, and reflection on, performance—all in service of potentially creating improved methods. Further, the ideas discussed in this special issue have the potential to be differentially applied within and across such a training cycle. Specifically, research could explore the testing and application of techniques within training research and development but borne out of a collaboration between the sports and military sciences. For example, a technique such as anticipation training (Ward et al., 2008/this issue), suggests that both low-tech and high-tech preparatory methods manipulating temporal occlusion could be implemented prior to a given training session (i.e., used in support of learning during pre-process training). Similarly, techniques such as self-talk (Tenenbaum, Edmonds, and Eccles, 2008/this issue) could be tested during actual execution. Alternatively, the type of strategic scheduling of attention Eccles (2008/this issue) might also be adaptable to more complex learning environments in support of in-process interactions.

As for post-process interaction, an interesting adaptation would be to consider the types of psychophysiological assessment described by Janelle and Hatfield (2008/this issue) to understand interactions of emotion and attention but do so during after-action review. In particular, given the degree of discomfort trainees can experience when discussing errors in performance, research might help us better understand how to mitigate the potentially negative effects of such stressors as might occur when reflecting on performance during debriefing. More generally, the techniques described by Williams, Ericsson, Ward, and Eccles (2008/this is-
issue) to capture performance effectively in dynamic, real-world situations could be adapted not only for in-process execution but could be explored at the pre- and post-process level to help determine the degree to which differences may exist in how experts effectively brief and debrief.

We view this as an area of low-risk collaboration with a high potential for payoff. Of course, not all techniques used within sports will be appropriate for, or applicable to, training for the military. But, as the articles in this special issue illustrate, there exists enough overlap to motivate a programmatic research effort where military and sports sciences evaluate and adapt each other’s methods across a continuous training cycle of pre-, in-, and post-process interventions to integrate preparation, execution, and reflection.

In the next section we discuss how an understanding of learning and expertise can be better understood by more thoroughly exploring the development of expertise.

UNDERSTANDING THE DIMENSIONS OF EXPERTISE

A necessary component of expertise studies is the need for differentiation and classification of proficiency at various levels. As noted in the learning sciences, although “research on expertise has provided characterizations of novice and expert performance in many domains, the progression from novice to expert has not been extensively examined. Describing such a progression or trajectory toward expertise would be instructionally informative” (Lajoie, 2003, p. 22). Furthermore, as pointed out in studies of expertise in naturalistic settings, in much of the research, those participants characterized as novices are really “naïves,” and those described as experts are often times only apprentices or journeymen (Hoffman, 1998). More importantly, there has been little research in trying to understand the progression from expert-to-master (as studied historiographically by Simonton, 1990, 2004).

Along these lines, modern research often distinguishes expert and nonexpert performance not as a developmental continuum but as a discrete difference between experts and novices. In order for us to truly understand expertise and its development, we must have a more fine-grained explication of two intermingled issues—that of defining expertise and that of measuring expertise. Scientifically, the debate is centered on problems with defining expertise in the absence of conceptual and operational definitions that span the proficiency continuum. Hoffman (1998) argued for thinking about expertise research in terms of a continuum of proficiency. He provided a set of conceptual definitions from which we might build a better specified set of operational definitions that could drive the development of expertise. These conceptual definitions help us to more fully communicate something about the development of expertise even if they are merely labels we use as place-holders as the operational definitions are realized. Table 1 presents these conceptual definitions we see as a useful starting point for consideration in devel-
oping our understanding of a proficiency continuum for expertise studies (see related distinction from others in philosophy and computer science, Dreyfus and Dreyfus, 1986, or in the military, e.g., Fuhr, 2005; Kennedy, 2002).

The search for useful operational definitions is a particularly important collaborative endeavor and an outstanding challenge. For instance, one might operationally define experts as people who show reliable superior performance in controlled tasks (Ericsson & Smith, 1991), but in the real world expertise is often distinguished by the ability to adapt rapidly to tough and novel tasks having no known or easy solution (Hoffman, 1998). Creating a domain and organizationally appropriate proficiency scale is no easy matter and necessitates the use of multiple and converging measures (cf. Hoffman, Coffey, & Ford, 2000). But a strong foundation exists that could help meet such a goal. For example, like no other field, sports is replete with quantitative and statistical analysis of performance. As such, it has a rich tradition of “ranking” performance. Similarly, the military continually develops varied proficiency levels within its training programs. Nonetheless, neither of these disciplines has systematically integrated this notion of the proficiency continuum as articulated by Hoffman (1998), an idea based upon centuries-old tradi-

<table>
<thead>
<tr>
<th>Level of Expertise</th>
<th>Conceptual Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naïve</td>
<td>No experience with the domain</td>
</tr>
<tr>
<td>Novice</td>
<td>Someone who is new—a probationary member. There has been some (“minimal”) exposure to the domain</td>
</tr>
<tr>
<td>Initiate</td>
<td>Someone who has been through an initiation ceremony—a novice who has begun introductory instruction</td>
</tr>
<tr>
<td>Apprentice</td>
<td>Someone 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</td>
</tr>
<tr>
<td>Journeyman</td>
<td>Someone 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</td>
</tr>
<tr>
<td>Expert</td>
<td>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</td>
</tr>
<tr>
<td>Master</td>
<td>Traditionally, a master is any journeyman or expert who is also qualified to teach those at a lower level. In some areas, a master was 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 subdomain knowledge</td>
</tr>
</tbody>
</table>
tions in guild training. Collaboration between the military and sport sciences could support research on how to augment the aforementioned conceptual definitions in service of developing usable operational definitions.

We next discuss candidate research propositions for how it may be possible to accelerate progression along the proficiency continuum.

ACCELERATING THE DEVELOPMENT OF EXPERTISE

Typically, in the development of learning content, the trainer must first understand the nature of the knowledge and skills to be acquired and then go from that understanding to a specification of the required learning and practice materials. We suggest that, if we hope to accelerate the trajectory along the proficiency continuum, this is a necessary but not sufficient condition. What is additionally required is an explanation of the appropriate concepts, adapted from extant hypotheses about learning, from which one could draw to devise training that instills expertise at differing levels, and in particular the skills of adaptation to tough cases. Specifically, as just discussed, collaboration between the military and sports sciences could lead to not only the development of multiple measures to operationalize Hoffman’s (1998) conceptual definitions of expertise but also the identification of the most appropriate learning and practice materials for training within and across proficiency levels.

This is perhaps the most critical issue for collaboration from both the theoretical and practical perspective; that is, a fuller understanding of how to instill expertise and especially how we can accelerate learning. This notion of accelerated learning in the context of expertise 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 deliberate practice (Chase & Simon, 1973; Ericsson, Krampe, & Tesch-Romer, 1993), suggesting that it is not possible to accelerate expertise development. Nonetheless, it is clear that developing expertise takes significant time, and research to help us understand why, and to potentially increase, in some way, the speed with which it can be acquired, would be of value. Specifically, while we have a strong foundation of knowledge and theory on expertise, we know much less about how this can be translated into training knowledge and skills for a variety of operational settings. 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.

What is required in support of this goal is consideration of trainee variation in skill levels as well as identification of which hypotheses about learning may be applicable. Obviously, multiple hypotheses are necessary to cover research on training across the entire proficiency continuum. In Table 2 below, we discuss a set of
### TABLE 2
Expertise Level and Representative Research Hypotheses

<table>
<thead>
<tr>
<th>Level of Expertise</th>
<th>Representative Research Directions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Naïve</strong></td>
<td>The naïve has no experience with the domain, suggesting that significant scaffolding of rudimentary concepts is necessary. Here hypotheses supporting research on concept acquisition using carefully monitored experiential learning settings may be beneficial (Kolb, 1984). Most simply, experiential learning argues for iterative learning cycles, where the trainee first concretely experiences learning content through hands-on practice and then reflects upon that experience while trying to abstract key ideas. Along this vein, research can examine how this can be tested using the types of simulation systems developed in the military (see Fiore, Metcalf, &amp; McDaniell, 2007 for a discussion). Here the simulations may require limited contextualization, that is, partial representation of the operational setting, where only the critical environmental factors are included so as not to overwhelm the learner.</td>
</tr>
<tr>
<td><strong>Novice</strong></td>
<td>Novices have had minimal exposure to a domain, so knowledge acquisition and concept formation is still in its early stages. Here hypotheses to test the benefits of learning from errors (e.g., Bjork, 1994) and more carefully developed metacognitive processes such as self-regulation of learning (e.g., Schraw, 1998) may be efficacious. Although learning from errors might be beneficial at certain other stages, we emphasize it here because it is in these early stages that the foundational knowledge is being acquired. Self-regulation training and/or learning from errors could be integrated with the types of simulation supported experiential learning settings to which naïve learners had just been exposed. The additional element at this stage would be modifying the scenarios within the simulation such that they emphasize common misconceptions, that is, correct reductive or flawed mental models (cf. Gentner &amp; Stevens, 1983). In this way the trainee is exposed to content that is situationally grounded but which also leads them to understand how some aspect of performance (e.g., a particular decision) can lead to errors.</td>
</tr>
<tr>
<td><strong>Initiate</strong></td>
<td>The initiate has begun introductory studies and would benefit from a richer context for concept acquisition and integration and one populated with more challenging content. Although one might argue that that the same could be said for learners at all levels, we emphasize it here because the learner is likely to be at stage where he/she can deal with enhanced complexity of the content (i.e., manage the contextual richness), while at the same time adequately applying concepts acquired during earlier stages. For example, hypotheses drawn from problem-based learning (see Jonassen, 2007), or case-based learning (e.g., Lundeberg, Levin, &amp; Harrington, 2000), where examples help the learner bind the concepts he has acquired, along with seeing their application, would be beneficial. Again, here we can increase the complexity of the simulation-supported experiential learning environments by developing a richer training context that incorporates elements of these hypotheses.</td>
</tr>
<tr>
<td><strong>Apprentice</strong></td>
<td>The apprentice is well beyond introductory studies and is now working closely with one of higher skills; as such, hypotheses testing of ideas related to cognitive apprenticeship may be warranted (e.g., Collins, Brown, &amp; Newman, 1989). For example, drawing on the situated nature of learning, Collins et al. suggest that effective mentors use 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 own performance. This could be implemented with simulation-based environments or practiced in the field.</td>
</tr>
</tbody>
</table>
Journeyman  
Because the journeyman is able to perform competent work unsupervised, Feltovich, Spiro, and Coulson’s (1997) notion of cognitive flexibility, where difficult and varied learning situations are presented, may be useful (see also Spiro, Feltovich, Jacobson, & Coulson, 1992). Although cognitive flexibility–based training would also benefit apprentices, we emphasize it at this level because 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 journeymen level might independently use simulation-based environments to train on these types of learning situations. Note, though, that an important element of cognitive flexibility is the creation and resolution of “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, feedback within a system (e.g., intelligent avatars) or expert mentoring is critical at this point.

Expert  
When one is at the level of expert, where one performs domain-specific tasks reliably and accurately and is able to handle rare cases, the transition is more to a role of training support. Here the expert participates in systematic knowledge elicitation, where his knowledge is used to help develop future training for those less experienced (Crandall, Klein, & Hoffman, 2007; Hoffman, Shadbolt, Burton, & Klein, 1995). Further, an important outcome of knowledge elicitation is that, during the process, knowledge is invariably discovered, enabling important additions to training programs while also leading to an improved understanding of expertise at higher levels. In particular, experts come to acquire understanding of rare cases, that is, those particular problems or decisions that occur only approximately 5% of the time. Simulations of rare cases experienced by other experts, and discovered through knowledge elicitation, may help time compress the learning process even for experts (e.g., Hoffman & Fiore, 2007).

Master  
There is less research at the level of master; that is, those who establish standards and regulations for task performance. Specifically, we do not know how to turn experts into masters, if we define master as one who is qualified to teach (i.e., be a mentor to apprentices). Further, it is also unclear how to identify journeymen who have the skills to be good mentors. As such, an important research issue involves identification of the idiosyncratic skill set that suggests that one has the ability to actively support creation of appropriate learning content and mentor those less experienced. Further, in the context of hypotheses concerning masters and mentors, what the field truly needs is an epistemologically valid theory of expert mentoring. Hoffman (1998) has described the characteristics of the expert mentor, which includes development of rich mental models of the learner’s knowledge and skill. From this the expert mentor is able to anticipate when the learner will form a reductive mental model, anticipate the kinds of cases that will lead the learner to form a reductive model, and the kinds of practice experiences that will force the learner to go beyond his current reductive models. We bring this up because the large body of work on coaching from the sports sciences may be applicable in applied studies of expertise.
research directions based upon some of the extant hypotheses about learning—a set meant to be merely representative of how to consider accelerating the development of expertise. In particular, we wish to point out the primary conceptual issues for each stage of the proficiency continuum to highlight the sorts of hypotheses that might be developed in support of training design and development. Although some of these hypotheses are relevant across multiple levels, our goal with selecting from a number of these is to highlight how the varied hypotheses themselves can point us toward a number of potentially productive research directions. We ground these research directions in simulation-based training given the tremendous advances that have been made in technologies supporting high-, medium-, and low-fidelity training environments along with reductions in cost for such systems.

In short, training research can pursue experimentation where varied instructional strategies are tailored in such a way that they appropriately scaffold learning as people progress along the proficiency continuum. In Figure 1 we illustrate how the aforementioned ideas can be used to conceptualize an approach for advancing our understanding of expertise development. By attending to learning across a training cycle, which consists of learning episodes bounded by preparation and reflection, we can investigate the types of instructional interventions, methods of measurement, and form of content most appropriate for use before, during, and after particular learning episodes imposed by a training curriculum. Here we suggest that future research pursue the varied approaches as articulated in this special issue.
and integrate ideas for performance improvements using approaches to training and measurement that may accelerate movement along the proficiency continuum. What we hope to illustrate is that an interdisciplinary science of expertise is possible. This requires an integration of the ideas described in this special issue; that is, the concepts and methods potentially of use to both the military and sports sciences. In this way, the military may be able to realize the goal of accelerating the development of expertise.

CONCLUSIONS

As mentioned at the outset of this special issue, stress and performance, skill acquisition, attentional control, and emotion regulation are all important aspects of military human factors. Therefore, as these concepts mature in other fields such as sports psychology, it becomes imperative that military researchers are aware of relevant developments. More specifically, there is a need to determine which factors of performance coming out of the sports sciences might contribute to our understanding of effective performance in the military and better specify how and why they contribute. In this special issue we have presented theory and methods so as to begin to facilitate cross-fertilization between the sports and military sciences in service of developing theoretical and methodological extensions leading us toward interdisciplinary theories of expertise. It is now up to the research community to consider whether the methodological extensions are feasible and the degree to which theoretical advances are possible.

There are potentially far-reaching implications of findings from the sport sciences for other disciplines. The more researchers understand, for example, the foundational elements of stress in athletic performance, the better able they will be to offer guidance on developing stress mitigation/reduction strategies. Similarly, increased understanding of attentional control on the part of athletes may, in due time, increase the speed at which this can be mastered in a variety of domains. Finally, a richer understanding of skill acquisition may truly lead us to develop training strategies that accelerate the development of expertise. In sum, the broader the conceptualizing, and the more richly specified the concepts, the more likely it is that researchers will develop and offer accurate principles and guidelines as well as effective tools and interventions that facilitate performance. We hope this special issue takes us closer, and motivates others, to continue to investigate the complementarity between the military and sports sciences.

ACKNOWLEDGMENTS

Development of this special issue and the writing of this article were partially supported by Grant Number SBE0350345 from the National Science Foundation and
by funding by Grant Number N000140610118 from the Office of Naval Research. The second author’s contribution was partially supported through participation in the Advanced Decision Architectures Collaborative Technology Alliance, sponsored by the U.S. Army Research Laboratory under Cooperative Agreement DAAD19-01-2-0009. We thank Florian Jentsch for comments on an earlier version of this manuscript. The opinions and views of the authors are their own and do not necessarily reflect the opinions of the University of Central Florida, the National Science Foundation, the Office of Naval Research, the U.S. Army Research Laboratory, or the U.S. government.

REFERENCES


