Facilitating Team Adaptivity in a Dynamic and Complex Tactical Environment

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ABSTRACT

Research suggests that experts across many domains exhibit deficiencies in knowledge and skill that prevent them from achieving a more advanced level of expertise referred to as *adaptive expertise*. These deficiencies include undetected misperceptions, shallow comprehension of complex concepts, and knowledge that is not well integrated. A training system designed to address deficiencies such as these and improve tactical team adaptivity is being developed for use in U.S. Air Force Distributed Mission Training (DMT) exercises and F-16 squadrons. This system, called the Cognition-Centered Constructivistic Program of Instruction (C3PI), is designed to improve aircrew adaptivity by helping aircrews visualize the execution of their tactical standards, and by facilitating the acquisition of richer and more comprehensive knowledge about those standards, including knowledge that helps them both use and adapt them across a wide range of situations.

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ADAPTIVE EXPERTISE

Adaptive expertise refers to the fluent use of skills, strategies, and knowledge to respond appropriately and effectively to challenges and unpredicted events that arise during task performance. This type of expertise depends upon an accumulation of experience, the development of a repertoire or response strategies, and a deep comprehension of complex and dynamic concepts and relationships within a given domain (e.g., Holyoak, 1991; Kozlowski, 1998). Deep comprehension supported by an organizational framework capable of representing complex and dynamic domain knowledge helps experts to recognize the current situation and identify relevant experiences, skills, and strategies that should be utilized to determine and guide their response.

In teams, adaptivity depends upon the basic elements of adaptive expertise described in the paragraph above, plus much more. Adaptive teams are "able to make the necessary modifications in order to meet new challenges;" "proactive and flexible, able to modify internal processes and external actions to achieve their objectives;" and "prepared to respond to uncertain situations (Klein and Pierce, 2001, pp. 2-3)." Members of adaptive teams anticipate one another's decisions and actions and effectively and proactively communicate their own (e.g., Stout, Cannon-Bowers, Salas, & Milanovich, 1999). In addition, members of adaptive teams have a shared and accurate understanding of the overall situation, or *big picture*, and of how the team should function within a given situation (e.g., Bergondy, Fowlkes, Gualtieri, & Salas 1998; Stout, 1995; Stout et al., 1999). Klein and Pierce (2001) further suggest that adaptive teams:

- anticipate problem areas;
- adopt a proactive problem detection mindset;
- prepare for modifying a planned course of action during mission execution;
- maintain awareness of the big picture so that immediate goals don't overtake objectives;
- maintain a good sense of the given situation, including its affordances (i.e., features that can be used to one's advantage);
- develop experience solving problems as a team; and
- develop a repertoire of problem solving routines.

Three of the characteristics of adaptive teams listed above address preparation – specifically, preparation for the execution of a tactical mission (i.e., the first three items in the above list); two address the team's knowledge of the unfolding situation (i.e., the fourth and fifth items in the above list); and two refer to the accumulation of problem solving experience and routines (i.e., the last two items in the above list). Thus, according to this set of characteristics, team adaptivity depends on knowledge, accumulated experience and routines, and also on preparation skills and strategies.

The importance of routines to expertise is echoed by Shalin and her colleagues (1997). These researchers note that expertise is characterized by the compilation and use of *accepted methods*, which are very similar to the 'routines' referenced by Klein and Pierce (2001). Shalin et al. promote a view of adaptive expertise that emphasizes both the importance of human responsiveness to specific details of the task environment and the complementary "influence of knowledge on the execution of actions … in the form of pre-determined, accepted methods (p. 201)." This view is consistent, as these researchers point out, with the Recognition-Primed (RPD) model of rapid expert decision making (e.g., Klein 1993). According the RPD model, once experts recognize a situation as familiar, they choose a response based on their memory of responses used in the past and their effectiveness.

Another characteristic of adaptive expertise that contributes to adaptivity – both at the individual and team level – is that of skill and knowledge generalizability. That is, adaptive experts should be able to, for any given situation, access relevant knowledge and response strategies in order to respond in an effective and fluent manner. Feltovich, Spiro, & Coulson (1993) contend that adaptive experts should be able to apply knowledge "flexibly in diverse, ill-structured, and sometimes novel contexts," and identify the acquisition of this type of expertise as *advanced knowledge acquisition*. Others have similarly characterized advanced expert knowledge as highly integrated and thus generalizable (e.g., Ericsson, 1996).

ACQUIRING ADAPTIVE EXPERTISE

The section above describes some of the ways researchers and theorists have characterized adaptive experts and teams. In this section, we identify ways in which experts and teams may fall short of the expectations implied by those characterizations, and discuss three different types of strategies that may be used to enhance adaptive expertise and team adaptivity. As noted above, team adaptivity "depends upon the basic elements of adaptive expertise…plus much more". In line with the first part of this definition, we view adaptive teams as consisting of adaptive experts, and consider research and theory on adaptive expertise and ways in which its acquisition could be improved to be equally relevant to both individuals and teams.

An example of a common barrier to the attainment of adaptive expertise is the development of misconceptions during advanced learning stages. Feltovich, Spiro, and Coulson (1993), for example, found the development of misconceptions to be pervasive in medical students they studied, and additionally found the misconceptions to be associated with performance problems that included the development of inaccurate methods and a limited ability to use knowledge flexibly due to an inadequate conceptual knowledge structure. A related problem identified by these researchers is that of expert knowledge that does not adequately capture the intricacies and complexities of complicated concepts and relationships. Feltovich et al. blame a tendency for both instructors and students to oversimplify complex concepts, and suggest means by which the training of complex conceptual knowledge might be improved.

As another example of an expertise acquisition problem that hinders the attainment of adaptive expertise, Lewandowsky and Kirsner (2000) found evidence suggesting that expertise, as it is typically trained and acquired, may be partitioned into separate parcels, consistent with the *knowledge encapsulation framework* proposed by Boshuizen and Schmidt (1992). More specifically, Lewandowsky and Kirsner found that expert bush fire fighters used different rules to predict the spread of fires, depending on the fire context (i.e., fire fighting or back burning). As additional evidence in support of the context-specific encapsulation of knowledge, these researchers cite work by Marchant, Robinson, Anderson, and Schadewald (1991). In that study, requiring subjects to perform additional processing of the specific case in which a rule was applied interfered with the ability of experts, but not novices, to recognize the applicability of that rule to another case. Thus, due at least partially to the tendency to refine their expertise to the contexts within which they operate (e.g., Chase & Ericsson, 1981; Chase & Simon, 1973), experts may acquire knowledge that is relatively inflexible in its application across situations.

As noted by Klein and Pierce (2001), relatively little has been written about adaptivity with respect teams, and likewise, relatively little research has been conducted on the topic. Problems associated with acquiring adaptive expertise are relevant to team adaptivity based on the assumption that teams have the most potential to perform adaptively when they consist of adaptive experts. However, as noted previously, adaptivity in teams requires more than just adaptive individuals. Further, because team adaptivity has received relatively little attention, it is likely that there is much work that can be done to better understand and facilitate it.

Hence, evidence suggests that experts often fall short of achieving adaptive expertise and that insufficient attention may be given to facilitating team adaptivity. Below we describe three types of strategies that may be brought to bear to help improve this situation. These strategy types include: (1) training strategies; (2) task/mission preparation strategies; and (3) the establishment of boundaries and accepted methods. Although other types of strategies, such as performance support strategies, may similarly benefit adaptivity, these three were chosen based on their influence on the design of an adaptivity-enhancing technology that will be described in a later section of this paper. This adaptivity-enhancing technology is being developed to support team adaptivity, in particular. Accordingly, whereas many strategies described below are relevant to individual-level adaptive expertise, they are all, to some degree, relevant to facilitating team adaptivity.

Training to Improve Adaptivity

One obvious type of strategy for facilitating team adaptivity is that of training. Based on their work with army Stability and Support Operations (SASO) teams, Klein and Pierce (2001) proposed a set of training objectives targeted toward the attainment of adaptivity in tactical teams. Targeting these objectives, listed below, constitutes a team adaptivity training strategy:

- develop a large repertoire of problem solving routines;
- develop a repertoire of self-organizing mechanisms (e.g., timelines);
- train for anomalies, workarounds, and replanning;
- develop a proactive "adaptation mindset", e.g., by including at least one malfunction or breakdown in each training exercise or scenario;
- calibrate common ground;
- train for both external and internal adaptation;
- train to manage more degrees of freedom;

_ train communication workarounds;
_ train information seeking skills;
_ train to rapidly "parse" a task (so parts of task can be reallocated); and
_ train to appreciate the team's affordances/resources and understand how they can be used most strategically.

Feltovich et al. (1993) proposed a set of training principles that target the acquisition of adaptive expertise, as well as the related form of expertise they refer to as *cognitive flexibility*. These principles focus, in particular, on reducing expert misconceptions, reducing the compartmentalization of knowledge, and improving comprehension and retention of complex material across domains. A subset of the principles primarily addresses the prevention and correction of misconceptions in addition to the comprehension and retention of complex material. These principles, which are also relevant to enhancing team adaptivity, encourage educators and training personnel to:
_ anticipate pre-existing trainee beliefs and interpretive models that may lead to the development of misconceptions about the concepts to be learned;
_ directly challenge likely misconceptions;
_ use multiple analogies and representations to teach concepts;
_ resist oversimplification and use techniques that aid comprehension of complex concepts;
_ use active training techniques that encourage the use and manipulation of knowledge that is being acquired; and
_ teach conceptual knowledge in the context of how it will be applied during task performance.

Another subset of the principles Feltovich et al. (1993) put forth addresses the problems of knowledge compartmentalization, as well as the comprehension and retention of complex material. These principles, which, again, are relevant to team adaptivity, encourage educators and training personnel to:
_ help trainees focus on clusters of related concepts, not individual concepts;
_ emphasize connections, conceptual dependencies, and concept variations across contexts;
_ help trainees gain expertise in the application of knowledge (e.g., expose them to numerous strategically-chosen cases that highlight critical knowledge application challenges and strategies);
_ emphasize and demonstrate relationships among cases and between cases and concepts; and
_ revisit cases and concepts from different points of view and with respect to different types of goals.

Lewandowsky, Dunn, Kirsner, and Randell (1997) empirically evaluated a method for building integrated knowledge that is consistent with principles proposed by Feltovich et al.. This method involved providing one group of study participants with an *integrative diagram* at the outset of their training. The diagram summarized the roles of all relevant factors involved in the physics of fire. In effect, it served as a framework that both conveyed the complexity of the domain and provided an integrative structure to help trainees organize knowledge they acquired about the domain. Compared with the performance of trainees who learned to control simulated bush fires in the absence of specific instructions, trainees who learned after seeing the integrative diagram were more accurate in their decision making and were more likely to consider terrain slope in addition to wind effects. This finding suggests that the integrative diagram was an effective training tool for enhancing complex conceptual knowledge that is critical to adaptive performance. Other techniques that have been identified as consistent with the Feltovich et al. training principles for improved cognitive flexibility, especially when used together, include deliberate practice, adoption of multiple perspectives, disequilibrium experiences (i.e., events that challenge the trainees' assumptions and strategies), and scaffolding techniques (e.g., Ross and Pierce, 2000).

Mission Preparation Strategies

Mission preparation represents another opportunity, in addition to training, to help individuals and teams improve their ability to perform adaptively. For example, preparation and planning periods are opportunities to work on developing many of the characteristics Klein and Pierce (2001) have attributed to adaptive teams (see list above in Adaptive Expertise section of this paper). In addition, Klein and Miller (1999) note that adaptive teams tend to generate expectancies and identify inconsistencies and planning shortfalls during the mission planning process. Other researchers have found the skills and strategies used by adaptive teams to include developing contingency plans (e.g., Bergondy et al., 1998), developing contingency plans that are thorough (e.g., Macmillan, Entin, & Serfaty, 1993), identifying problem areas (e.g., Crane, 1999), questioning assumptions (e.g., MacMillan et al., 1993; Spiker, Nullmeyer, Tourville, & Silverman, 1997; Spiker, Nullmeyer, & Tourville, 2001), describing and rehearsing situation-specific radio calls (e.g., Nullmeyer, Crane, Cicero, & Spiker, 2000), and using a what-iffing strategy to evaluate the plan (e.g., Crane, 1999; Spiker et al., 1997, 2001).

Both empirical evidence and expert opinion suggest that adaptivity is benefited by planning that is not overly detailed (e.g., Miller, 2001). That is, plans that support adaptivity must be flexible and provide room for adjusting and adapting. As an example, during the mission brief, a retired F-16 instructor pilot interviewed in support of this effort would specify general strategies and rules of thumb that his team should keep in mind. However, he would not specify details about when those strategies and rules of thumb should be implemented.

Planning is furthermore an opportunity to facilitate adaptivity by helping team members develop *shared mental models* that provide them with an understanding of teammates' expectations, responsibilities, and informational requirements (e.g, Stout, 1995; Stout et al., 1999). Bergondy, Fowlkes, Gualtieri, and Salas (1998) assert that, during the mission brief, it is critical that naval air wing members develop compatible mental models (in which knowledge is appropriately and strategically shared) of the mission, and that in the execution phase it is critical for them to update these models, and use them to identify deviations from the plan and to guide interactions with other team members. Direct evidence supporting these roles of shared and complementary mental models in team adaptivity is lacking (possibly due to the difficulty associated with measuring mental models). However, the hypothesis is supported by research showing that teamwork training and interpositional knowledge training, training techniques that should foster the convergence of team member mental models, enhance team performance (e.g., Cooke et al., 2000). Shared mental models are thought to be the means by which planning helps team members use proactive communication strategies and anticipate the information needs of their teammates (e.g., Stout, 1993). In addition, it has been suggested that shared mental models allow teams to use implicit coordination strategies (e.g., Gualtieri, Bergondy, Oser, & Fowlkes, 1998). That is, team members are thought to act and make decisions based on these shared models in order to maintain adaptivity when high workload conditions inhibit overt communication.

Boundaries and Accepted Methods

Training and preparation strategies such as those described above support adaptivity in a number of ways. For example, these strategies (1) help decision makers detect situations that require adaptation; (2) equip decision makers with knowledge and experience that support selection and execution of an effective response; (3) help decision makers anticipate and plan for specific events that would require adaptivity; and (4) help teams of decision makers adapt in a coordinated way. Another type of strategy that contributes to each of these four elements of adaptivity is the use of boundaries and accepted methods. By defining the realm of typical and expected events, boundaries help decision makers detect situations that require adaptation. By defining the realm of typical and expected responses, accepted methods both help decision makers more quickly select and execute a response. In addition, they allow team members to better anticipate one another's responses. That is, boundaries and accepted methods support the establishment of *shared knowledge* or *common ground* within a team which, similar to shared mental models, should facilitate team coordination and adaptivity.

Accepted methods and boundaries can also support adaptivity in the ways high level plans do. More specifically, they can take the form of general strategies, specific strategies that serve as baseline examples, and constraints that influence, but don't specify, the exact response strategy. Thus, they guide decision makers, but at the same time give decision makers room to adapt their response as they see fit for a particular situation.

As an example, accepted methods and boundaries within the domain of F-16 air combat are formalized in their *tactical standards*. These standards are "meant to serve as a common baseline of understanding across the F-16 community" in support of effective air-to-air operations and training (USAF Weapons School, 2000, p.2). Each F-16 squadron adapts these standards to meet their own needs and to address lessons learned, while at the same time maintaining consistency with higher level guidance and other squadrons. Together, these standards represent a framework that guides decision making and execution. Thus, team members have a shared understanding of how an air combat mission should generally unfold and how they should, in general, respond to various mission events. At the same time, the standards are intended to be used as guidance, and, thus, leave room for adapting. This approach to air combat teamwork is consistent with the notion, expressed above, that the development of a high-level plan that does not specify exact details can contribute significantly to team adaptivity. Further, the F-16 tactical standards are intended to capture and convey squadron expertise, and thus provide a vehicle for capturing "lessons of the advanced tactical training community (USAF Weapons School, 2000, p.3)," squadron 'lessons-learned,' and expertise and knowledge within the F-16 community, in general.

Building Team Adaptivity in the F-16 Air Combat Domain

The F-16 air combat domain is one in which adaptivity is critical. The F-16 air-to-air combat environment is especially dynamic and fluid, and the challenge of preparing for that environment cannot be underestimated. Training for air-to-air combat involves becoming very familiar with tactics, radar mechanics, communication, targeting, etc. prior to delving into the challenges associated with team coordination and complex mission execution. Although it makes sense to learn the basics of the job well before learning the complexities of performing that job in a dynamic, fluid, and time pressured team environment, it is arguably the case that insufficient attention is often paid to training at that advanced end of the training continuum. For example, the F-16 community cites problems affecting advanced training that include a significant reduction in training exposures over the past decade and the absence of certain types of information and realism from training scenarios (USAF Weapons School, 2000).

To help address this situation, the Warfighter Training Research Division of the Air Force Research Laboratory's Human Effectiveness Directorate (AFRL/HEA) is leading an ongoing program of training research utilizing a 4-ship F-16 Distributed Mission Training (DMT) testbed in their Mesa, Arizona facility. Approximately 12 times per year, two teams of four pilots and two weapons controllers come to the laboratory for a week-long training research exercise. They fly together as a 4-ship team for nine missions designed to provide progressive exposure to a range of combat scenarios. The missions involve briefing and debriefing sessions in addition to the time spent in the F-16 simulators (Schvaneveldt, Tucker, Castillo, & Bennett, 2001). The project discussed here involves supplementing DMT with a training system, called the Cognition-Centered Constructivistic Program of Instruction, or C3PI, that can be used during the mission phases of planning/preparation, briefing, and debriefing. Specifically, C3PI will support 4-ship teams in visualizing and evaluating different situations and ways in which tactical standards might be applied within them during each of these mission phases. Thus, C3PI will contribute to the next generation of brief/debrief technology and mission planning training technology to be implemented within DMT. In addition, it is being designed so that it may be used by individual squadrons as both a training and mission preparation tool.

The primary objective of C3PI is to help the F-16 community enhance team adaptivity, both within DMT exercises and, ultimately, within each squadron facility, as well. To this end, C3PI incorporates training principles and strategies mentioned above; planning strategies, such as what-iffing and the identification of problem areas; and boundaries and accepted methods. In particular, the objective of C3PI is to contribute to the enhancement of team adaptivity using means that:

- help pilots become proficient at envisioning the battlespace and assessing situations by helping them acquire expertise:
  - translating radar data and radio calls into a 3-dimensional mental picture of the relevant battlespace and
  - using ranges and position information to make sound decisions under time pressure;
- build pilots' repertoire of problem solving routines and strategies (i.e., experience applying the tactical standards);
- help pilots better understand when and how to apply routines and strategies by:
  - giving them experience applying and adapting them across a range of scenarios and
  - identifying and correcting relevant misconceptions; and
- enrich pilots' knowledge with expert advice specific to given scenarios and standards.

METHOD

The first steps involved in designing C3PI included (1) reviewing research and theory on team adaptivity and (2) conducting a training requirements analysis. The review of research and theory was performed to identify relevant principles of advanced learning and skill acquisition and to identify common deficiencies in the skill and knowledge of experienced task performers. These principles and deficiencies, many of which are described above, have influenced C3PI design decisions and, more generally, the C3PI design. The training requirements analysis consisted of conducting unstructured and structured interviews with subject matter experts (SMEs) and observing DMT exercises, including exercise mission briefs and after action reviews (AARs). The interviews focused on the identification of challenging situations faced by F-16 crews and expert-novice differences in responding to those situations.

After identifying training requirements and principles associated with adaptive expertise in the F-16 air combat domain, we began to develop the C3PI design. To design C3PI, we are using an iterative storyboarding approach and working closely with SMEs. In addition, storyboard walkthroughs are periodically conducted with SMEs. These walkthroughs provide SMEs with an opportunity to provide feedback on the C3PI design and to envision and suggest ways in which C3PI capabilities and technologies could be improved and extended to address related performance support requirements. In addition, SMEs are helping the design team focus C3PI training scenarios on difficult decision points and challenging situations, and are assisting with the technical details needed to support the training provided by C3PI.

By working closely with SMEs, we are able to incorporate adaptive expertise training philosophies and objectives into C3PI in ways that are consistent with training philosophies of the F-16 community, that take into account F-16 tactical procedures and constraints, and that are enriched with SME knowledge. Further, by working closely with SMEs, we hope to design C3PI in ways that will optimally support the F-16 community.

C3PI DESIGN SOLUTION

C3PI will be a PC-based system that demonstrates tactical standards using multimedia presentations. Our goal is to enable aircrew to better visualize, understand and apply tactical standards, focusing initially on the air-to-air domain. Our focus on tactical standards stems from their importance to team execution in a dynamic environment, especially for aviation teams. The standards provide a baseline for execution performance and allow aircrews to anticipate one another's performance. This is crucial in a highly dynamic, stressful, and communications-limited environment.

Aircrews will interface with C3PI via a PC-based visualization environment that allows them to select, view, interact with, and modify scenarios involving air-to-air threat presentations. C3PI will be delivered with a library of scenarios based on standards found in Air Force Tactics Techniques and Procedures (AFTTP) 3-1. These scenarios can be used 'as is' with C3PI. In addition, squadrons can tailor the basic scenario set, within allowable constraints, to create scenarios that reflect their squadron standards. There are two primary modes in which users will interact with C3PI—the *demonstration mode* and the *interaction mode*.

Demonstrate Tactical Standards

In the demonstration mode, C3PI will bring squadron standards "to life," presenting air-to-air tactics integrated with communications. Scenarios will run in real time, showing responses of each of the members of a 4-ship in response to threat presentations. Scenarios will reflect real world distances, speeds, maneuvers, and tactics whenever feasible. Users will be able to play, stop, pause, rewind, and fast forward the scenario. In addition, radar displays from each member of the 4-ship can be opened and positioned on the screen as desired, providing another way to view the situation. Tactical ranges shown in Table 1, which are crucial to the decision making that occurs during air-to-air engagements, can also be shown.

Thus, the demonstration mode provides users with an interface to visualize tactically meaningful information and observe important triggers to team actions and tactically sound responses. Users can compare scenarios and extract important elements of the tactical environment, potentially augmenting their experiences.

Table 1. Information That Can be Viewed When Using C3PI in its Demonstration Mode

Selectable Types of Information
• Depiction of speaking entities and communication network usage to illustrate communication priorities • Radar sorting actions • Radar volume • Aircraft tracks • Picture range • Targeting range • Minimum out range (MOR) • Minimum abort range (MAR) • Factor range • Shot depth • Mission plan details (e.g., overview of a game plan and contracts) associated with the chosen scenario

Interactive Mode

The interactive mode of C3PI provides a way for users to apply their knowledge of tactical standards and to "what if" different responses. Table 2 shows examples of decision points that occur during the mission phases of an air-to-air engagement. At each decision point, aviators using C3PI will be able to select a tactic or action and observe its execution. For example, during the detection phase, in response to "picture" information about the tactical situation, users can select a tactic (e.g., wall or grind) and then decide how the tactic will be implemented. Users can replan this decision to compare and contrast responses or continue to the next decision point. Users will also be able to compare their own responses with standards specified in AFTTP 3-1 or with squadron standards, and they will have access to expert advice and information. Thus, in this way users will be able to build their knowledge, experience, and understanding of standards. Table 2 also shows that each decision made can be linked to mission essential competencies being developed by AFRL/HEA to capture important tactical processes.

Table 2. Combat Mission Decision Points

C3PI Decision Point	Mission Phase	Decision Actions	Mission Essential Competency
1.Picture information from AWACS/GCI	Detect	• Select tactic • Select tactic employment	• Detects factor groups in area of responsibility • Organizes forces to enable combat employment
2. Picture Range		• Select tactic • Select tactic employment	• Detects factor groups in area of responsibility • Organizes forces to enable combat employment
3. Targeting Range	Target/ Intercept	• Targeting	• Intercepts and targets factor groups
		• Radar sort	• Intercepts and targets factor groups
	Engage	• Decide whether shot criteria met	• Employs ordnance against valid hostile targets and/or denies enemy weapons in accordance with mission objectives
4.Minimum out/abort ranges	Follow-on	• Check shot status • Check action range • Decide on follow-on shots • Select flow direction	• Determines and initiates appropriate follow-on actions • Remains oriented to force requirements
5. Egress		• Conducts cold ops • Repeat from Decision Point 2	• Remains oriented to force requirements

DISCUSSION

If an instructional system developed for air combat pilots is to be used, the system must capture pilots' interest, be easy to learn and use, offer useful information, offer training exercises with a range of durations including very short durations, produce a return on time invested quickly, and be perceived as valuable by the users (e.g., by enhancing performance in noticeable and measurable ways). Furthermore, if such a system is to be used, it should be *developed by the warfighter for the warfighter*. Thus, F-16 SMEs play a critical and significant role in the design of C3PI, helping to design not only the capabilities of the technology that warfighters will utilize to improve their mission performance, but also the manner in which warfighters will engage with that technology to maximize the potential improvements.

C3PI is first and foremost designed as a tool that the F-16 community can use to build adaptive expertise and facilitate team adaptivity. To this end, it will help pilots visualize the execution of tactical standards under different tactical conditions, and facilitate the acquisition of richer and more comprehensive knowledge about those standards, including when and how to use them, and when and how to adapt them. In addition, C3PI will support the F-16 community by providing squadrons and training facilities a means of capturing and updating tactical standards.

In addition to serving as a training tool and repository for tactical standards, C3PI can be used during mission briefs and AARs to help crews visualize and discuss various tactical situations, plans, possible outcomes (during the brief), and actual outcomes (during the AAR). Used in this way, C3PI would enhance shared knowledge of a crew with respect to a specific mission, improve the crew's ability to identify and consider contingencies, and refresh the crew's memory of strategies and procedures relevant to a given mission immediately prior to its execution. In this role, C3PI contributes to the Air Force vision for enhanced training of mission planning, briefing, and debriefing skills. Accordingly, it may be used to supplement a suite of tools currently being developed to support planning, briefing, and debriefing.

C3PI will be developed with cross-platform compatibility and thus can be used at training facilities (e.g., the AFRL/HEA DMT facility), squadrons, and even on personal computers and laptops. It is anticipated that C3PI could be easily adapted to support air combat teams using other platforms, and that the C3PI concept and capabilities may be used to support training across a wide range of domains. Further, C3PI may be extended to further support the F-16 domain. As an example, a useful extension may involve the development of intelligence within C3PI (e.g., in the form of an agent) that helps a trainee to understand the ways in which a particular decision, tactic, or tactic implementation may make them vulnerable.

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