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## Exploration of Sensemaking in the Education of Novices to the Complex Cognitive Work Domain of Air Traffic Control

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Exploration of Sensemaking in the Education of Novices to the Complex Cognitive Work

Domain of Air Traffic Control

By

Travis J. Wiltshire

B.S., University of Central Florida 2009

A Thesis Submitted to the  
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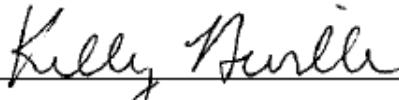
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By: Travis J. Wiltshire

This thesis was prepared under the direction of the candidate's thesis committee chair, Kelly Neville, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

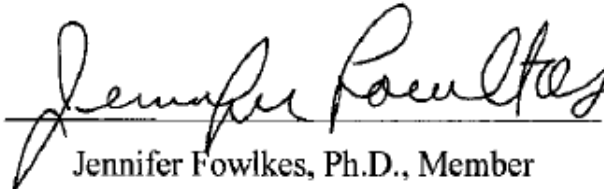
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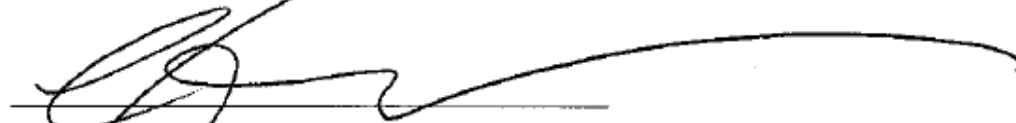
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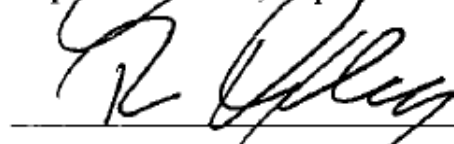
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## **Abstract**

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Many current complex business and industry jobs consist primarily of cognitive work; however, current approaches to training may be inadequate for this type of work (Hoffman, Feltovich, Fiore, Klein, & Ziebell, 2009). To try and improve training and education for cognitive work, Klein and Baxter (2006) have proposed cognitive transformation theory (CTT), a learning theory that claims that sensemaking activities are essential for acquiring expertise that is adaptive and thus well suited for cognitive work domains. In the present research, cognitive task analysis methods were used to identify and assess sensemaking support in the instruction and learning of complex concepts by two experienced air traffic control professors and seven of their students. The goal of this research was to compare instructional strategies used in an academic setting with the predictions of CTT to gain insight into strategies for the application of CTT. Cognitive task analysis methods employed included course observation, artifact examination, and knowledge elicitation sessions with two professors and seven of their students. Knowledge elicitation transcriptions were coded using categories derived from CTT and the data/frame theory of sensemaking (e.g. Klein, Moon, & Hoffman, 2006; Sieck, Klein, Peluso, Smith, & Harris-Thompson, 2007) to assess theoretical and applied implications for learning and instruction in a complex domain. Findings are represented by synthesizing theory driven predictions with grounded training strategies and technologies. In addition, recommendations are advanced for applying CTT to training and educational systems in order to provide sensemaking support during early phases of learning from which expertise may be developed.

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## **List of Abbreviations**

ATC.....	Air traffic control
ATCT .....	Air traffic control tower
CDM .....	Critical decision method
CTA.....	Cognitive task analysis
CTT .....	Cognitive transformation theory
FAA.....	Federal Aviation Administration
IO .....	Intelligence officer
SBT .....	Scenario based training
WAA.....	Work action analysis

## **Introduction**

Many high stakes and complex professional work domains require extensive training and education before practitioners begin to obtain the proficiencies required for that domain.

Training challenges are of critical importance as many United States government organizations are facing the impending retirement of the practitioners who are capable of handling the most complex challenges (e.g., Hoffman, Feltovich, Fiore, Klein & Ziebell, 2009). Based on review of expertise literature comparing novices to experts, acquiring expertise in complex domains can take 10 or more years (Ericsson, Krampe, & Tesch-Romer, 1993). Other research has indicated that even when experts' knowledge is imparted to novices, as measured through recall and recognition based evaluations, they are often unable to develop the ability to apply the knowledge to novel situations (Bransford, Franks, Vye, & Sherwood, 1989).

These findings are problematic because the nature of these domains is complex, and technological advances in these domains often involve new ways to present more information. As a result of these changes, practitioners are facing increasing cognitive demands (Hoffman & Fiore, 2007). Both practitioners and educators in complex cognitive work domains need to learn to "understand, complex, dynamic, and evolving situations" in order for appropriate actions to be taken (Klein, Phillips, Rall, & Peluso, 2007). More generally, the people and organizations of the United States, striving to remain globally competent, can benefit from research that investigates opportunities for accelerating learning such that the time required to develop expertise in complex cognitive work domains is reduced.

This thesis research investigated, in an academic setting, the education of novices in the complex cognitive work domain of air traffic control (ATC). The research is based on a theory of sensemaking; according to this theory, expertise in cognitive work domains hinges on

sensemaking learning activities that continually refine and attune a person's knowledge and organization of knowledge such that the perceptions, motor responses, and decisions that define a person's interactions with the work environment steadily become more fluent and flexible (e.g. Klein & Baxter, 2006; Klein, Moon, & Hoffman, 2006b; Sieck, Klein, Peluso, Smith, & Harris-Thompson, 2007). The high-level goal of this research is to assess learning, teaching, training, and instructional theory and research regarding how the acquisition of expertise is best supported in comparison with actual educational practices in the domain of air traffic control (ATC). To represent the findings of this research, theory driven predictions are synthesized with grounded training strategies and technologies to advance applications of CTT for both learning and teaching that may facilitate expertise acquisition in cognitive work domains.

In the sections that comprise the literature review, the theoretical and empirical foundations of this research will be discussed. First, relevant background on the nature of expertise, how experts differ from novices, and a review of empirical studies that support the concept that the acceleration of expertise may be attainable are presented. Next, the *data/frame theory of sensemaking* (Klein et al., 2006b; Sieck et al., 2007) will be discussed to provide the foundation for a discussion of *cognitive transformation theory* (CTT; Klein & Baxter, 2006). CTT is a learning theory that claims sensemaking activities are essential for developing expertise in a cognitive work domain. CTT and the sensemaking learning components for developing expertise in cognitive work, as proposed in CTT and extended in this research, will be discussed. Lastly, a short review of research that lends insight into nature of the complex cognitive work involved in ATC is presented. This is followed with an introduction to the research methods employed in this study as well as the objectives of this research.

## Expertise

To summarize all the definitions of expertise would be beyond the scope of this research; rather, three relevant definitions are presented. According to Ericsson et al. (1993), an expert is an individual with mastery of the most difficult skills in a domain; skills which are developed through the active regulation of their performance by assessing the application of their skills and the resulting outcomes on the environment over an average of 10 years. Hoffman et al. (2009) describe experts as individuals with extensive domain knowledge obtained from their past experience, which enables them to act effectively in uncertain and complex situations by recognizing subtle features that others do not notice. Lastly, Klein (2009) asserts that an expert is not simply an individual who gains more and more experiences, but someone who learns lessons from experience and uses those lessons to sophisticate his or her understanding of how things work.

Decades of expertise research suggests that experts are distinguishable from novices due to their ability to attend to, organize, represent, and interpret information from their environment in ways that support fluent performance (Bransford & Cocking, 2000; Chi, Feltovich, & Glaser, 1981). More specifically, Bransford and Cocking emphasize that novices and experts differ in six key ways. First, experts are able to recognize meaningful patterns and features that novices do not. Second, expert knowledge is organized in more meaningful ways that reflect a deep conceptual understanding of their domain, as opposed to the list of facts and formulas that novice's knowledge is often based upon. Third, the knowledge of experts is not limited to isolated applications and is organized in ways that are generalizable to other sets of domain-specific circumstances. Fourth, experts are capable of exerting minimal attentional efforts to retrieve relevant pieces of knowledge or information from memory. Fifth, although an expert's

knowledge is highly organized, it is not guaranteed that they will be able to impart or teach their knowledge to others. Finally, some experts are able to solve novel situations within their domain with flexibility while others tend to approach problems in procedural, rule-based ways that are more rigid.

Research has shown that as people become experts they acquire a deep conceptual understanding of a domain that provides an organizational framework that allows experts to make sense of situations, draw upon applicable past experiences, and select the relevant knowledge and/or strategies that will produce the desired effective response (e.g., Chi et al., 1981). This is consistent with Klein's (1993, 1998) model of recognition primed decision-making (RPD) derived from the study of expert decision-making in real-world domains such as firefighting, nursing, and weather forecasting. According to the RPD model, experts draw on prior experience to diagnose the typicality of the current situation based on a small set of cues. Once a situation or aspects of a situation are recognized as familiar, experts can quickly determine which actions would be effective based on responses selected in the past.

**Adaptive and routine expertise.** Bransford and Cocking (2000) suggest that there are at least two possible types of expertise that an individual can acquire. The first type, routine or rigid expertise, is characterized by individuals that follow a strict formula and inflexibly apply their extensive knowledge and skills. Routine experts are able to learn to apply their skills more quickly and accurately as they gain experience; however, they fail to enrich their conceptual knowledge (Hatano & Inagaki, 1986). The second type, adaptive or flexible expertise, is characterized by individuals that are continually seeking to learn and improve upon their current skills. Adaptive experts are described as being able to fluently and effectively apply their skills, strategies, and knowledge in unfamiliar and ambiguous circumstances (e.g., Bransford &



Cocking, 2000; Hatano & Inagaki, 1986; Neville, Fowlkes, Castillo, & Nullmeyer, 2003).

Though the literature suggests that there are two types of expertise, research has not established a true dichotomy between the types. Therefore, Schwartz, Bransford, and Sears (2005) suggest that the two types of experts exist along a continuum. Along this continuum, routine experts' performance is highly efficient, yet deficient in novel situations that require innovation, whereas, adaptive experts are both highly efficient and highly innovative in novel situations.

Feltovich, Spiro, and Coulson (1993) characterize the nature of real world complex domains as ill-structured thus requiring that an expert is able to apply his or her knowledge flexibly to differing and novel situations. Spiro, Collins, Thota, and Feltovich (2003) refer to the ability of individuals to apply knowledge flexibly as *cognitive flexibility*. The construct of cognitive flexibility, which Spiro et al. characterize as supporting the adaptation of prior experience and conceptual understanding to new contexts that differ greatly from the contexts in which the knowledge was acquired, can be an essential component of adaptive expertise (e.g., Hoffman et al., 2009). Furthermore, adaptive expertise entails being able to perform skills efficiently while maintaining a conceptual understanding of the underlying principles that support these skills (Bransford & Cocking, 2000; Chi et al., 1981).

Schwartz et al. (2005) posit that routine expertise may be effective in a static domain; however, many domains are increasingly dynamic and require flexible problem solving due to rapid changes in technology and the effects those changes have in sociotechnical environments (e.g., van Merriënboer, Jelsma, & Paas, 1992). Current sociotechnical organizations are facing training challenges as work is becoming more complex and technology places an increased cognitive demand on practitioners (e.g., Fiore, Cuevas, & Oser, 2003; van Merriënboer et al., 1992). The changes primarily influencing cognitive work are due to technological advancements

that cause shifting goals, development of new types of data, and implementation of novel display types (Hoffman & Fiore, 2007). Moreover, Ericsson (2006) asserts that the reliance on the routine application of skills is a challenge to the development of more advanced expertise. Therefore, a greater need, now more than ever, exists for experts who are able to apply their knowledge flexibly and adaptively. As such, throughout the rest of this thesis, any mention of expertise in cognitive work is associated with the capabilities of adaptive experts rather than those of routine experts.

### **Expertise Acquisition**

Now that novices, experts, and types of expertise have been differentiated, this section will discuss research that describes the processes for acquiring expertise. Review of expert performance suggests that the acquisition of expertise over a minimum of 10 years is supported by research across domains including: chess, music, mathematics, and athletics (Ericsson et al., 1993). In chess, Simon and Chase (1973) found that there was not an individual that had obtained the international title of chess grandmaster without at least 10 years of intense chess preparation. Raskin (1936) found that, on average, prominent scientists and authors published their first works at 25 years of age, yet their most renowned work followed approximately 10 years later. In music composition, Hayes (1981) calculated that an average of 20 years occurred between the time when an individual first started studying music and when their first outstanding piece of music was composed. More specifically, Hayes found that individuals who started studying music under 6-years-old composed their first prominent composition about 16.5 years later and individuals who started between the ages of 6–9 produced their first renowned composition 20 or more years later.

Research emphasizing that time and practice are the only requirements for reaching high levels of expert performance can be misleading. Ericsson et al. (1993) assert that 10 years of experience within a particular domain is not sufficient for the development of expertise without *deliberate practice*. The researchers contend that deliberate practice is characterized by the learner's motivation to invest his or her time and effort in order to improve performance; that an instructor that has an understanding of the learner's preexisting knowledge must be available in order to provide the learner with immediate feedback about his or her performance; and finally, the learner must engage him or herself in repetition of the task. Deliberate practice, according to Ericsson (2006), allows individuals to approach demanding tasks with a problem solving approach resulting in advances in learning and improvement.

**Training strategies that accelerate the acquisition of expertise.** This section describes research that accelerates learning, beyond basic deliberate practice, suggesting that the time required to gain expertise can be reduced given the implementation of the right training strategy. Training strategies to accelerate the acquisition of expertise require further exploration as Crandall, Klein, and Hoffman (2006) discuss the tendency for instruction and training to teach only procedures and rarely focus on important perceptual discriminations that support the flexible application of knowledge. Because experts are able to recognize meaningful patterns that novices do not (e.g. Bransford & Cocking, 2000; Hoffman & Fiore, 2007; Klein, 1998), research that investigates whether novices can be taught the perceptual cues that matter should be beneficial for the design of instruction that aims to support expertise acquisition for cognitive work domains (e.g. Bransford & Cocking, 2000; Klein & Baxter, 2006). To this end, a short review of several empirical studies examining perceptual learning is presented along with a discussion of how the findings contribute to accelerating the acquisition of expertise.

Biederman and Shiffrar (1987) conducted a study to determine whether novices could be taught to use the perceptual cues that experts use in a difficult perceptual task. The task was to judge the sex of day-old chicks. The sexing of day old chicks is regarded as an extremely difficult perceptual task in which experts are capable of executing judgments at 98% accuracy with 1,000 chicks sorted per hour. For this study, subject matter experts estimated that it took professionals within this domain approximately 2.4 months to approach 95% accuracy and 2-6 years to approach 98% or greater accuracy.

The study compared the sex discrimination of novices given cue training with that of experts using 18 difficult chick photographs; where the experts were either current or retired practitioners within the domain. After their first trial, the novices received training in which they were shown diagrams that emphasized perceptual discriminations between the chick sexes. The training differentiated the two sexes by describing the various contours to look for to accurately determine the sex. The results of the study indicated that, as a result of the training, novice performance was better than the performance of the experts. More specifically, experts identified the correct chick sex 72% of the time; whereas, after training, the novices correctly identified the chick sex 84% of the time. The findings of this study suggest that for a difficult perceptual task, novices trained on what cues to look for and where to look for those cues can reduce the time required for making perceptual discriminations at the level of an expert.

Guerlain et al. (2004) conducted research to determine if training could mitigate the extremely high percentage of errors made performing laparoscopic cholecystectomy during the first thirty procedures that surgeons performed. Guerlain et al. found that structured perceptual learning modules can reduce the time required for perceptual and cognitive learning in a complex laparoscopic surgery task. Traditionally, novices in the laparoscopic surgery domain learn

initially by observing others perform the procedure and then begin practicing on live patients. There is a large degree of anatomical variation in this domain, thus the probability that novices will make errors is high.

Results from the study (pretest vs. posttest) indicated that using structured perceptual learning video clips helped novice surgeons to discriminate the most salient perceptual cues from the task-relevant perceptual cues (i.e. what cues are irrelevant vs. what cues are important); whereas, those given unstructured training were not able to make the same discriminations. This training is beneficial to the surgeons because they are able to non-intrusively differentiate between anatomical variations in multiple patients before they actually perform a live surgery. The surgeons were trained to discriminate the cues that matter for the safety and success of the surgery from the cues that are irrelevant. The researchers conclude that the results of the study suggest “perceptual learning modules can condense perceptual learning processes that occur over extended time” (Guerlain et al., 2004, p. 701).

Findings from Doane, Alterton, Sohn, and Pelligrino (1996) suggest the criticality of initial training methods to the long term development of expertise. The experiment was designed to assess the effects of initial training on the acquisition and transfer of both stimulus specific knowledge and strategic knowledge that was not specific to a certain stimuli. The conditions were initial training with easy perceptual contrasts versus complex perceptual contrasts. In the easy contrast condition, stimuli were initially easy to differentiate because the stimuli were dissimilar. Then, the stimuli became more complex as the participants went through subsequent trials. In the complex contrast condition, stimuli were initially complex, in that the stimuli were very similar, and as participants progressed through trials, the complexity decreased.

Participants who were initially trained on easy discriminations imprecisely compared stimuli on the basis of a global comparison strategy in which participants looked for a minimum number of points or looked at the entire shape. The participants applied this strategy even after significant exposure to complex discriminations that showed them that the strategy was inefficient for those discriminations. Contrarily, participants initially trained with complex discriminations developed a discrimination strategy that made use of the finer details of specific stimuli in which perceptual discrimination was more efficiently executed as a result of the refined strategy learned from the more complex discriminations.

Based on the rigid strategy adopted by participants initially trained with the easy discriminations as well as their failure to reach performance levels achieved by those in the initially complex training condition, the researchers infer that the difficulty of initial training could have a long lasting effect on future performance. This study shows the importance of selecting training strategies when first trained on a particular task or possibly within a domain, such that when the goal is developing adaptive expertise rather than routine expertise, selected training strategies should account for the long lasting effects on the resulting skills and strategies developed.

### **The Role of Mental Model Formation in Adaptive Expertise Acquisition**

The acceleration of learning does not just aim to hasten the acquisition of standard proficiency or skills; it also aims to develop adaptive expertise that is well suited for success in complex domains (Hoffman et al., 2009). According to Klein and Baxter (2006), declarative knowledge, routines and procedures, recognition of familiar patterns, perceptual discrimination skills, and the continual formation of increasingly accurate mental models are the forms of knowledge that should be acquired to facilitate expertise in cognitive work domains. Further,

Klein and Baxter argue that the traditional instructional approach consisting of providing a learner with knowledge, allowing an opportunity for practice, and providing feedback is effective for teaching declarative knowledge and routines or procedures; but is ineffective for teaching people to recognize familiar patterns, make difficult perceptual discriminations, and develop and maintain accurate mental models.

Hoffman et al. (2010) likewise suggest that most current complex business, industry, and military jobs consist primarily of cognitive work and that current approaches to training may be inadequate for that type of work. To try and improve training for cognitive work, Klein and Baxter (2006) have proposed cognitive transformation theory (CTT). CTT is a learning theory that claims sensemaking activities are requisite for learning in a cognitive work domain.

In the sections that follow, CTT and the data/frame theory of sensemaking (Klein, Moon, & Hoffman, 2006b; Sieck et al., 2007), on which CTT is reliant, will be discussed. Following the theory descriptions, sensemaking learning components that derive from CTT and which may accelerate learning and the acquisition of adaptive expertise are presented. First, however, the *mental model* construct, central to both CTT and the data/frame theory of sensemaking, is described.

**Mental models.** There are differing perspectives on the utility and definition of the mental model construct. In the case of CTT, Klein and Baxter (2006) define a mental model as a cluster of causal beliefs that explain the relationships among occurring events such that an individual's mental model of a given domain represents the core causal relationships that explain and predict how events will unfold. Regarding conceptual learning in science education, Chi (2008) describes a mental model as a structured collection of individual beliefs that represent a concept or a system of interacting concepts in the external world. In human factors, Wilson

(2000) contends that a mental model is a mental representation of a system that elucidates the relations of the various structures or functions within the system. Klein, Moon, and Hoffman (2006a) extend the definition of a mental model to include, “a memory representation, with a salient mental imagery component, depicting states of affairs but linked to or expressed in terms of concepts, principles, and knowledge” (p. 71). More specific to complex task training, Fiore et al. (2003) define a mental model as “task specific, integrated long-term memory structures that develop during training, and are activated during task performance” (p.188).

Klein and Baxter (2006) indicate that the formation of a mental model involves making sense of conflicting or confusing data that leads to a change in the way someone thinks about and sees things. Mental models are changed as people gain experience and recognize inaccuracies within their mental models. When people obtain information in conflict with their mental model, they are able to revise their mental models to accommodate that information and thereby ensure increasing accuracy of the mental model (Chi, 2008; Crandall et al., 2006; Klein & Baxter, 2006).

Chi (2008) studied the formation of mental models during the learning of complex material and concluded that individual beliefs can be added to mental models and ‘gaps’ in knowledge can easily be filled by providing an individual with the missing information. Also during the learning of complex material, Chi describes the categorization of concepts to be beneficial to the formation of a mental model, as attributes and features associated with a category can often be inferred and assigned to a concept. To illustrate this notion, Chi uses the example of the ability to infer that a robin lays eggs even when never explicitly told that a robin lays eggs. If it is known that a robin is a bird and that birds lay eggs then it can be inferred that robins lay eggs.



Klein and Baxter (2006) suggest that novices of a complex domain, in an attempt to comprehend causal relationships, may expend a great amount of effort to develop a mental model; however, the model is often under-developed and inaccurate. In novices, Klein and Baxter propose that the formation of rudimentary mental models relies on the process of sensemaking. Klein and Baxter also posit that sensemaking is essential for experts to revise and add to their mental models. In the following section, the data/frame theory of sensemaking and the research which led to the development of the theory are reviewed.

### **The Data/Frame Theory of Sensemaking**

Sensemaking can be described as the deliberate cognitive effort required to understand connections amongst information or between events in order to predict outcomes and adapt performance based on those predictions (Klein et al., 2006a; Klein, Phillips, Rall, & Peluso, 2007). Sieck et al. (2007) describe a number of naturalistic studies they conducted over a three year period to assess novice-expert differences in the sensemaking processes and mental models of military intelligence officers (IOs). These studies led to the development of a model of sensemaking.

Sieck and his colleagues conducted a three phase research program where each phase lasted approximately one year. In Phase 1, the researchers required novice and experienced IOs to participate in a series of scenarios that would challenge their sensemaking. The participants were required to think aloud throughout the scenarios and the researchers transcribed all comments and coded them based on the types of inferences, speculations, and explanations they contained. Within Phase 1, the researchers also collected real-world data on the sensemaking ability of drivers to reorient themselves once they had become lost. From the results of Phase 1, a preliminary model of sensemaking was derived.

During Phase 2, the researchers' goal was to gain a better understanding of the cognitive processes which occur in ambiguous situations in the real-world and to refine the data/frame model. They used three cognitive task analysis (CTA) methods referred to as a Sensemaking Knowledge Audit, Critical Decision Method (CDM), and a Sensemaking Interview to collect data and gain further insight into IO sensemaking. These CTA methods allowed the researchers to explore sensemaking of real-world incidents in which IOs faced a sensemaking challenge to gain a richer and in depth look at the underlying mental processes of sensemaking. More specifically, the CDM was useful for examining circumstances when sensemaking failures occur and methods for improving sensemaking through training. Data from Phase 2 were used to produce a revised model of sensemaking.

Sieck et al.'s goal during Phase 3 was to further characterize the sensemaking differences between novices and experts in order to provide specific training recommendations. During phase 3, the researchers revisited and recoded the data derived from Phase 1. They then conducted scenario-based interviews with the IOs to examine whether novice/expert sensemaking differences were due either to sensemaking strategies or the stronger causal mental models of experts. The results of this three year study led to a very rich data/frame model of sensemaking that was developed, tested, refined, and supported over the course of data collection and analysis.

Central to Klein and his associates' theory of sensemaking (e.g. Klein et al., 2006b; Sieck et al., 2007) is the concept of a *frame*. The frame is a construct that is very similar to the mental model in that it serves to organize knowledge in a way that provides meaning to the situation. Klein and his associates define the process of sensemaking as fitting data into a frame, and fitting a frame around the data; however, both activities are required simultaneously, as a frame is used

to describe the data and the data are used to select the frame. The data/frame theory is illustrated by the model shown in Figure 1. According to Klein's et al.'s theory, sensemaking involves (a) elaboration of a frame through increases in complexity and additional data, (b) questioning the frame to ensure the data and frame fit and to assess the accuracy of the explanation provided by the frame, and finally (c) the process of reframing which consists of rejecting an inadequate frame to replace it with a superior one.

According to Klein et al. (2006b), a frame is the initial starting point, perspective, or framework which an individual uses to begin to make sense of events. A frame is a hypothesis about what data matter and how they are related. Klein et al. (2007) posit that mental models are a form that frames can take in order for prior experience to be used to predict and explain the causal relationships between events, thus leading to a deeper conceptual understanding. When a frame has effectively allowed the individual to make sense of data, the information or knowledge gained from the process of sensemaking becomes a part of that frame.

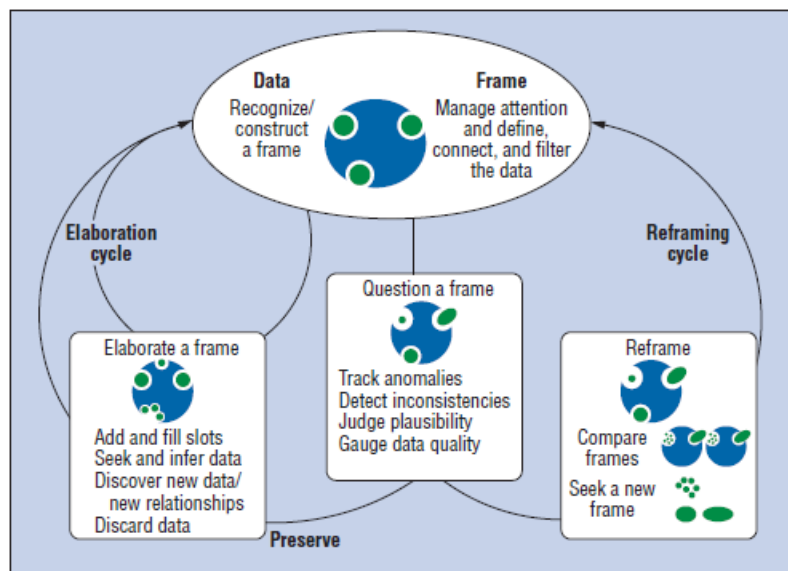


Figure 1. Model of data/frame theory of sensemaking (Klein et al., 2006b).

In the data/frame theory of sensemaking, the posited relationship between mental model formation and the use of mental models for running mental simulations is a *closed-loop transition sequence* (Klein et al., 2006b). According to Klein et al. (2006b), the sensemaking process depicted in Figure 1 contributes to formation of an explanatory mental model which can be used for explaining a current situation and to predict or anticipate possible outcomes by running a mental simulation. Similarly, Chi (2008) also indicates that a mental model is used to ‘run’ a mental simulation, such that dynamic events can be understood and predictions regarding outcomes can be generated. Klein and Baxter (2006) claim that the development of expertise in cognitive work is facilitated through the process of sensemaking.

### **Cognitive Transformation Theory**

Klein and Baxter (2006) argue that learning in a cognitive work domain is not a process of adding more information to an individuals’ ‘store’ of knowledge; rather, it relies upon the refining and attuning of a person's knowledge and organization of knowledge such that the perceptions, motor responses, and decisions that define a person's interactions with the work environment steadily become increasingly adapted for the work domain (e.g. Klein & Baxter, 2006; Klein et al., 2006b; Sieck et al., 2007). Cognitive transformation theory (CTT) describes the progression of expertise in cognitive work as dependent on the successive shedding of outmoded mental models and their replacement with increasingly accurate, rich, and nuanced mental models. In this theory, cognitive transformation is a mental model development process that an individual undergoes as he or she learns new material. CTT aims to facilitate the development of pattern recognition, perceptual discrimination skills, and the formation of increasingly accurate mental models.

To reiterate, Klein and Baxter (2006) suggest that developing expertise in cognitive work domains does not merely depend upon increasing the amount of factual knowledge; rather, acquiring expertise in cognitive work domains relies upon mental models and more importantly the ability to revise and discard mental models to support the growth and evolution of conceptual understandings that facilitate fluent and flexible performance. CTT hypothesizes that sensemaking is the central function through which learning for cognitive work is facilitated. Klein and Baxter (2006) posit that cognitive learning, essential for developing expertise in a cognitive work domain, is a sensemaking activity composed of the following four learning components:

1. Diagnostic assessments to identifying flaws in students' mental models,
2. Learning objectives that emphasize sensemaking and encourage reflection of new learning so that deeper and richer mental models are formed and revised,
3. Practice that incorporates sensemaking in that it gives students experience figuring out what data matter and in what contexts, when it may be appropriate to seek certain data, and the contexts when certain data may be irrelevant, and
4. Feedback that indicates how performance can be improved but also that prompts sensemaking so that students can seek and interpret feedback on their own.

The following sections aim to present research that supports or elaborates each of the four learning components advocated by CTT to contribute to the development of expertise in a cognitive work domain. As described by Crandall et al. (2006), these learning components may be valuable because they give trainees the opportunity to “explore, reflect, learn, work through confusion, and develop deeper and richer mental models while carrying out complex tasks” (p. 214).

**Diagnostic assessments to identify flaws in mental models.** The process of identifying flaws in students' mental models can be challenging though researchers and theorists have indicated that a diagnostic component is essential in the acquisition of complex knowledge (e.g. Chi, 2008; Ericsson et al., 1993; Feltovich et al., 1993; Klein & Baxter, 2006). A flaw in a mental model can be any conceptual inaccuracy, misconception, weakness, or simplification. This section describes literature and research relevant for designing and incorporating diagnostic assessments for identifying flaws in mental models into learning for complex cognitive work and concludes with the importance for unlearning identified flaws and misconceptions.

Feltovich et al. (1993) emphasize the importance of understanding the reasons students develop misconceptions. One way that misconceptions may develop is when complex subject matter is oversimplified by either the method the instructor uses to teach it or by the ways in which the student may reduce or compartmentalize the knowledge. Therefore, when designing any form of instruction it is vital to know what aspects of the subject matter are particularly difficult to grasp and understand the ways in which presentation of the material can elicit misconceptions in students. Feltovich et al. suggest that using multiple types of assessment methods is beneficial for identifying misconceptions developed by students.

Based on Chi et al.'s (1981) findings that an expert's knowledge is organized around the core concepts of a domain whereas a novice's knowledge is arranged around superficial facts, Bransford and Cocking (2000) assert that education should be designed in a way that supports students in developing accurate conceptual understandings of subject matter. It may seem that an expert would be the best choice for teaching novices as they possess extensive domain knowledge that is highly organized; however, experts may not be experienced with relevant instructional and learning principles. As such, Hoffman et al. (2009) posit learning for cognitive

work requires an instructor who is both an expert in a domain and an expert instructor because such an individual would be able to draw upon his or her experiences in order to predict the conceptual inaccuracies or flaws that may form in the students' mental models.

The use of cognitive task analysis (CTA) or knowledge elicitation methods, described by Crandall et al. (2006), can be used to identify flaws in a mental model (Klein & Baxter, 2006). Rowe and Cooke (1995), for example, conducted a study to evaluate four mental model assessment techniques during a training program for aircraft electronics maintenance. The techniques were derived from CTA methods and designed specifically for the aircraft electronics maintenance domain. In order to determine the accuracy of participants' mental models, results were compared to the knowledge of an expert within the domain. All of the assessment techniques were predictive of successful troubleshooting performance; however, results suggested that no single technique encompassed all facets of the mental model. The researchers argue that incorporating mental model assessment, diagnosis, and instruction into training programs can enhance trainee understanding and, as a result, performance within complex systems. It is important to note that Cooke and Rowe (1994) express difficulty in selecting the mental model assessment technique that is appropriate for the task or performance being trained and evaluated. Further research is warranted to compile results of varying techniques across multiple domains to help provide guidance for selecting the appropriate measures.

Benefits of incorporating mental model assessment methods into training for complex domains have also been shown by Scielzo, Fiore, Cuevas, and Salas (2002). Scielzo and his colleagues assessed mental model accuracy by providing two types of computer-based complex task training followed by measuring the organization of concepts with a card-sort task and an integrative knowledge assessment that targeted complex forms of knowledge. The researchers

found the measures to be diagnostic of the knowledge acquired by the participants and also predictive of the instructional effectiveness of the training methods.

In addition to diagnosis, Klein and Baxter (2006) posit that an individual must also be able to unlearn information in order to develop more accurate mental models; that the inability to identify and unlearn flaws in a mental model is one of the key challenges to the development of expertise in cognitive work domains. The authors argue that as more advanced mental models are developed, individuals actually discredit data that are inconsistent with their current mental model. Similar to this notion, Ericsson (2006) posits that the principal challenge to furthering expertise is the reliance on acquired mental representations that do not accommodate change or allow for the incorporation of novel approaches to problem solving. CTT proposes that the concept of unlearning should also be incorporated into education and training for cognitive work.

One method for facilitating unlearning, according to Klein and Baxter (2006), is to include training interventions that provide a baffling event or cause the student to fail. They assert that this type of intervention is necessary to cause students to lose faith in their mental model. In these interventions, students must deliberately try to discover what was wrong with the current mental model in order to revise or replace it. According to CTT, the diagnosis and unlearning of flaws and weaknesses in students' mental models is critical for ensuring successful learning in cognitive work domains and can be facilitated by incorporating expert instructors, multiple types of assessments, and interventions that induce unlearning.

**Learning objectives that emphasize sensemaking and encourage reflection.** Rapid technological changes in the work of sociotechnical environments increase the cognitive demands on domain practitioners such that training for cognitive work domains should focus on increasing reflective and adaptive mindsets in order to approach novel problems flexibly (e.g.



Feltovich et al., 1993; Hoffman et al., 2009; Klein et al., 2007; van Merriënboer et al., 1992). A goal of CTT is for learning objectives to emphasize sensemaking and encourage reflection on new learning in addition to just focusing on the declarative knowledge and procedures.

According to CTT, this is how deeper and richer mental models are formed, developed, and revised. Klein et al. (2006b) argue that an adaptive mindset provides motivation for individuals to actively make sense of situations through the deliberate questioning of frames and reframing. Furthermore, Klein et al. (2006b) suggest training students to employ sensemaking will be specific to a domain. That is, training should focus on creating richer frames in terms of strengthening causal relationships and discriminating anomalies students were previously unable to notice.

To facilitate an adaptive mindset, it may be necessary to demonstrate to students the fallibility of their mental models. CTT posits that as people gain experience they have difficulty developing more intricate mental models because they attempt to explain away information that is inconsistent or contrary to their current mental model. Likewise, Klein (1998) indicates that the recognition of one's limitations is a characteristic of expertise that is facilitated through reflection and critique of one's performance. Therefore, learning objectives for cognitive work must be designed to foster an environment in which people are encouraged to reflect on and recognize the flaws in their mental models so that students may develop an adaptive mindset (Klein & Baxter, 2006).

Bransford and Cocking (2000) describe adaptive experts as being metacognitive in that they engage in both a consistent process of questioning their level of expertise and continually learning to perform better. If metacognitive strategies can be incorporated into training, students may develop the adaptive mindset that is required for cognitive work domains. Metacognition

has been said to be predictive of effective learning in that it is the process through which humans monitor and control their cognitive processes in an effort to identify flaws or opportunities for improvement and then adjust learning strategies accordingly (Bransford & Cocking, 2000; Ford, Smith, Weissbein, Gully, & Salas, 1998; Redding, 1989).

Finding methods for incorporating metacognition into training for complex tasks may help students become capable of recognizing flaws in their mental models on their own as well as determining ways to improve the accuracy of their mental models. To this end, Vogel-Walcut, Fiore, Bowers, and Nicholson (2009) conducted a study to investigate the effects of *metacognitive prompts* on knowledge acquisition during scenario-based training (SBT). Metacognitive prompts can be described as a training intervention that induces metacognitive processes by requiring students to convey recently learned concepts in their own words. The results of the study indicated that trainees in the metacognitive prompting condition scored significantly higher on an integrated knowledge assessment; overall, the study indicated that metacognitive prompts have potential for increasing knowledge acquisition when compared to a training condition without metacognitive prompting.

In addition to facilitating the integrated acquisition of knowledge, Fiore and Vogel-Walcutt (2010) theorize that metacognitive prompts before, during, and after SBT could respectively facilitate: planning and preparation that allows the trainee to anticipate problems before training, active monitoring of performance during training to determine if he or she possesses an understanding that will lead to desired performance outcomes, and lastly, reflection after training that facilitates recognition of misconceptions to advance learning in later training and also receptiveness to feedback.

More importantly, if metacognitive prompting or strategies are designed into the early stages of training or exposure to a cognitive work domain, Fiore and Vogel-Walcutt (2010) suggest trainees may have the opportunity to build a stronger foundation of knowledge that will complement more advanced conceptual learning. The authors further propose that the incorporation of metacognitive prompts in early phases of learning may lead to a reduction in the overall training time. This emphasis on early stages of training is similar to the findings of Doane et al. (1996) in that the type of initial training conditions had a lasting effect on the strategies used, even when the initial strategy was no longer optimal.

Metacognition could encourage sensemaking and when applied to the learning context it could provide learners with a deeper conceptual understanding. Further research is warranted to determine to what extent metacognitive prompting encourages sensemaking and to what extent sensemaking benefits learning. In the present study, metacognitive prompting will be investigated in terms of whether there is any evidence of its use as a strategy for facilitating learning in a cognitive work domain.

**Practice that incorporates sensemaking.** CTT suggests that learning for cognitive work should involve practice that incorporates sensemaking in that it gives students experience figuring out what data matters and in what contexts, when it may be appropriate to seek certain data, and the contexts when certain data may be irrelevant. Bransford et al. (1989) contend that a pervasive problem throughout complex domains is that of possessing knowledge but failing to recognize the cues that indicate what knowledge is applicable within contexts other than the context in which the knowledge is learned. Bransford et al. suggest that this is a result of the common employment of instructional strategies that require learners to merely memorize terms and definitions as opposed to develop a complex conceptual understanding. Whitehead (1929)

put forth the term *inert knowledge*, which refers to knowledge the learner can only recall in specific contexts when the knowledge is in fact relevant to a multitude of contexts.

The problem of inert knowledge may be mitigated using instructional strategies that provide opportunities for practice that incorporate sensemaking. This type of practice would require students to apply their knowledge in varying contexts so that they may begin to recognize patterns and important perceptual cues that indicate when certain knowledge is applicable (Klein & Baxter, 2006). Examples of such instructional strategies may include: presenting students with complex cases, contrasting cases in conjunction with SBT, and contrasting cases in conjunction with a lecture. The rest of this section describes these three strategies.

In order to mitigate the problem of inert knowledge, Bransford et al. (1989) suggest less emphasis on fact acquisition and more on presenting students with complex cases. The researchers hypothesize this shift could lead students to both a better conceptual understanding and preparedness for solving complex problems in the future. Learning knowledge in the context of cases means that knowledge becomes integrated with cues, dynamic situational patterns, and other information that is part of the cases, thus leading to improved accessibility and integration with other context-relevant knowledge.

Fowlkes, Norman, Schatz, and Stagl (2009) propose that contrasting cases could deepen learning and possibly accelerate expertise acquisition when used in conjunction with simulation and SBT. The method is described as providing the learner with two or more related cases that are to be contrasted and compared. The cases should be selected based on differences, similarities, or dimensions that are fundamental to expert performance. The researchers posit that contrasting cases provides students with an opportunity to notice cues and features that are important for making distinctions between concepts and situations such that they are able to

perform effectively across varied contexts. If the findings regarding perceptual learning of Doane et al. (1996) can be applied to comparing and contrasting cases, then this strategy could demonstrate over time to the student subtle cues and contextual changes in situations, allowing for finer perceptual discriminations to be made and thus, leading to knowledge that is applicable in more situations.

A study by Schwartz and Bransford (1998) evaluated the effects of contrasting cases on student learning prior to classroom lecture. Students that contrasted cases and later received a lecture were able to predict outcomes of a hypothetical experiment better than students who read about features in a case and heard a lecture, summarized a relevant text and heard a lecture, or analyzed cases twice without hearing a lecture. The researchers found that providing students with contrasting cases, when followed by lecture, improved students ability to develop a deeper conceptual understanding of domain knowledge.

Contrasting cases and practice that exposes trainees to numerous real-world contexts, implemented in the education and training of students in cognitive work domains, have the potential to accelerate and deepen conceptual learning which can lead to expertise that is more adaptable and flexible (Hoffman et al., 2009). Thus, the strategies reviewed in this section (i.e., presenting students with complex cases, contrasting cases in conjunction with simulation and SBT, and contrasting cases in conjunction with a lecture) may provide students with the type of practice that incorporates sensemaking.

**Feedback that indicates how performance can be improved and prompts sensemaking.** CTT asserts that feedback should inform students how performance can be improved and encourage students to seek and interpret feedback on their own. That is, students should be encouraged to employ sensemaking in order to learn and strengthen causal

relationships and recognize cues they were previously unable to notice. Blickensderfer, Cannon-Bowers, and Salas (1997) indicate that feedback should inform students of the appropriate types of changes that need to be made to improve performance as well as precise times that the changes need to be made. The authors suggest that feedback is useful for helping students correct their mental model. Klein et al. (2006b) argue that knowing whether performance was correct or incorrect is not as informative as knowing how it was incorrect and how it can be corrected.

The type of feedback recommended by CTT and the data/frame theory is commonly referred to as *process feedback*, which is described by Blickensderfer et al. (1997) as feedback that “provides descriptive information on how the task was performed, how to improve performance, and changes which may be beneficial to performance” (p. 258). The authors indicate that process feedback is also referred to as ‘learning’ or ‘cognitive’ feedback. Similarly, they claim it is the feedback most relevant for the instruction of students of a complex domain. That is, process feedback gives students information about how to adjust their performance. Adjustments can range from purely procedural to conceptual, the latter of which would involve attunements to how the students perceive cause and effect relationships within the domain.

Klein & Baxter (2006) posit that although students benefit immediately from extrinsic feedback, students will benefit most from intrinsic feedback in the long term. Therefore, extrinsic feedback should be used sparingly so that the students learn to generate intrinsic feedback and do not become dependent on instructors and other external feedback sources. Students need to be able to determine on their own what contributed to a specific consequence, what events are irrelevant to their performance, and what cues indicate deeper causal relationships (Klein &

Baxter, 2006). If an instructor consistently provides feedback, students may begin to over-rely on it and will be ill-prepared to generate their own feedback to evaluate their own performance.

The process of using sensemaking to self-evaluate and generate intrinsic feedback is similar to the concept of *self-correction*. Blickensderfer et al. (1997) discuss *team self-correction*; however, their recommendations are applicable to individuals, not just teams. The authors describe self-correction as a natural mechanism in which teams or individuals correct their attitudes, behaviors, and cognitive activity without external intervention. Blickensderfer et al. focus on fostering self-correction in teams where opportunities to improve performance are emphasized, but more importantly for this research, is that it can foster deeper understanding and more accurate knowledge that contributes to the formation or increasingly accurate mental models.

### **Review of a Complex Cognitive Work Domain**

In theory, the acquisition of expertise in complex cognitive work domains is reliant upon the ability of people to continually improve their mental models by deliberate elaboration, identifying and unlearning the flaws in current mental models, and replacing inadequate mental models with better ones, all of which are supported by sensemaking (Klein & Baxter, 2006). This section aims to discuss the complex nature of the cognitive work domain that will be studied in this research as well as review the instructional strategies recommended by researchers of that work domain.

Seamster, Redding, Cannon, Ryder, and Purcell (1993) characterize complex work domains as domains in which personnel must perform multiple tasks, perform effectively under time constraints, handle dynamic and complex information, and coordinate with others. These are cognitive work demands and just as Klein and Baxter argue that a new type of training is

required for complex cognitive work, Seamster and his colleagues claim that a special type of expertise is required for complex domains. Experts in complex domains need not only domain knowledge, but also adaptive problem solving strategies that are effective in the time constrained, dynamic, and team coordinated work of that domain. Similarly, these experts must have strategies for prioritizing tasks and managing workload that are effective for complex, demanding cognitive work. The present research was conducted to evaluate the education of novices in air traffic control (ATC), a work domain involving extensive cognitive work and in which adaptive expertise is essential (van Merriënboer et al., 1992).

According to Durso and Manning (2008), air traffic controllers are responsible for the direction of aircraft both on the ground and in the air. On the ground, controllers must communicate and issue take-off and landing instructions to pilots. Controllers must maintain separation of aircraft throughout their departures, arrivals, and while in flight. Generally, controllers use views from a tower and different types of radar imaging systems to keep track of aircraft types, flight trajectories, and weather in order to supervise the flow of air traffic. Controllers are required to communicate with pilots and other controllers to support both the safe and expeditious flow of air traffic. In addition, controllers seek and interpret as many as 27 sources of data, as required by the dynamics and frequencies of the traffic, airspace, communications, and other factors in order to make sense of the situation and respond appropriately (see Durso & Manning, 2008).

The present research effort was pursued to identify and assess strategies used to teach and facilitate learning of complex material. The domain of ATC was used for this research because it involves a great deal of cognitive complexity (e.g., Durso & Manning, 2008; van Merriënboer et al., 1992). Prior research related to the instruction of ATC material is another source of relevant



training strategies. In particular, Seamster, Redding, and their colleagues (e.g., Redding et al. 1991; Seamster, et al., 1993) used cognitive task analysis (CTA) methods to elicit knowledge from expert and novice controllers in order to develop a framework for training required ATC knowledge and skills in the least amount of time. The researchers suggest training interventions based on an ATC expert mental model that they derived from their research. The expert mental model presents the organization of information in a way that is consistent with the cognitive work strategies of expert controllers. The researchers assert that the expert mental model could be used as a guide for training novices.

The ATC expertise research and modeling work of Seamster, Redding, and their colleagues suggests that decision-making in ATC relies on an accurate mental model of the current air traffic situation. Further, in order to develop a mental model representative of the current air traffic situation, ATC students must learn to manage their attention. Klein and Baxter (2006) argue that attention management is a sensemaking activity and that to perform it well, an individual must know what information to seek, when to seek that information, and what information is irrelevant and/or a potential distraction. Redding et al. (1991) posit that if ATC instruction were designed for students to associate procedures and strategies with relevant event types and situations, then students would more readily recognize what actions to take in a given situation and therefore, may require less information and time to make decisions.

Redding et al. suggest ATC students should engage in repetitive practice with dynamic event types so that they may begin to recognize event types and categorize information into more meaningful patterns. Redding et al. additionally propose a method of ATC instruction in which information is taught in incremental chunks, with each chunk followed by practice with ATC scenario simulations. This proposed method of ATC instruction is similar to Schwartz and

Bransford's (1998) and Fowlkes et al.'s (2009) conclusions regarding the deeper comprehension of material resulting from providing students with contrasting cases (i.e., event types) combined with a lecture and SBT in a simulated environment. These methods may support student sensemaking by increasing the contexts in which ATC students learn to apply their knowledge.

Seamster, Redding, and their colleagues (e.g., Redding et al. 1991; Seamster, et al., 1993) identified strategies, types of knowledge, and the knowledge organization of expert controllers, in order to provide recommendations for how to facilitate that expertise. The recommendations from Seamster, Redding, and their colleagues' work and the shared similarities with CTT, suggest that sensemaking is inextricably linked to learning in the ATC domain. This study aims to investigate approaches for achieving expert knowledge, strategies, and increasingly accurate mental models in complex cognitive work domains.

## **Research Approach**

Further research is warranted to determine the usefulness of CTT and assess its predictions about how complex material should be taught. ATC is a rich cognitive domain that provides the opportunity to find concrete examples of instructional strategies for complex cognitive work. These real-world strategies can be compared with Klein and Baxter's CTT to the extent they are consistent with CTT, they support the theory, and can serve as real world instantiations of it. These strategies may also suggest refinements to the theory. Findings that are inconsistent with the theory may suggest limits on the applicability of the theory or ways it should be adapted.

The sensemaking approach to learning proposed by Klein and Baxter (2006) could have beneficial implications for ATC instruction as well as a range of other domains. Embry-Riddle Aeronautical University's air traffic management curriculum is designed to prepare students for

success within a high stakes cognitive work domain. In addition to preparation for high stakes work, students are more immediately prepared for passing the Federal Aviation Administration's (FAA's) entrance exam. Instruction must be effective and, to that end, instructors are former controllers who, following long and successful ATC careers that included years as professional instructors, have invested significant effort into becoming university level ATC professors. Their credentials are further discussed in the methods section.

**Cognitive task analysis.** Naturalistic research methods, such as CTA, yield rich qualitative data that are able to illustrate cognition in ways that quantitative data often cannot. For example, Crandall et al. (2006) point out that the common measure of human performance, 'time to completion', does not provide insight regarding naturally occurring cognitive activity. CTA can be defined as "the study of cognition in real-world contexts and professional practice at work" (Crandall et al., 2006, p. vii). The researchers further assert that CTA methods are essential for identifying the requirements for developing training recommendations for cognitive work domains.

According to Crandall et al. (2006), a CTA study is characterized by the following three phases: (1) knowledge elicitation, (2) data analysis, and (3) knowledge representation. The researchers describe knowledge elicitation as the set of data collection methods used to obtain information about various knowledge and strategies that form the basis of performance. Knowledge elicitation methods primarily consist of observations, interviews, and self-reports; however, there are numerous other techniques (see Crandall et al., 2006). In CTA studies, data analysis consists of structuring the data in such a way that meaning is gleaned. There are numerous methods for analyzing CTA data; however, the coding process is the most prevalent method used to identify themes, cues, and patterns emergent within a data set. Lastly, knowledge

representation involves selecting the appropriate medium for communicating the findings from CTA data in a meaningful way.

Since a focus of this research is identifying strategies instructors use to teach in complex domains, observations were necessary for gaining objective insight and for framing the questions for knowledge elicitation sessions with professors and students. CTA methods were used to examine expert instruction of the complex concepts and skills involved in air traffic control tower (ATCT) controlling. Based on course observations and examination of course artifacts, the instruction of three complex cognitive tasks, same-runway separation, wake turbulence separation, and IFR separation were selected for examination in this research. These complex tasks are taught sequentially to ATCT students within a one month period. Knowledge elicitation sessions were conducted individually with both professors and students in order to gain insight into the teaching and learning processes occurring throughout this timeframe.

In the proposed research, teaching in an applied academic setting is explored by assessing teaching methods and student assessments of those methods and comparing them with predictions of CTT and Klein et al.'s theory of sensemaking. As argued by Klein (1998) and Crandall et al. (2006), research conducted outside the laboratory is useful for gaining insight, improved understanding, and a better foundation from which to develop research hypotheses and models that can be pursued in subsequent studies. Similarly, Pepperberg (2008) argues for the value of observation prior to devising a hypothesis as a strategy for identifying more innovative research questions that are grounded in a basic understanding of the variables, their dynamics, and external influences. The use of observation and other qualitative research methods may ultimately lead to more meaningful hypotheses including hypotheses that are suited to empirical testing.

**Validity of qualitative research.** Johnson (1997) criticizes the common misconception that the research constructs reliability and validity are only applicable to quantitative research methods. Qualitative research affords degrees of validity and reliability dependent on the conditions under which it is conducted. Johnson identifies three forms of validity that are applicable to qualitative research: Descriptive, interpretive, and theoretical validity. The three forms and strategies used to address them in the present research as recommended by Johnson (1997) are as follows.

First, *descriptive validity* is the degree to which researchers report an accurate depiction of phenomena being studied such that the description embodies the events that occurred. This study will address descriptive validity by means of researcher triangulation strategies in the analysis of the data (Johnson, 1997). One such strategy, *investigator triangulation* involves independent data evaluations. Data were analyzed by two coders, each with two years applicable experience as experimental psychology research assistants. Investigator triangulation was complemented by incorporating an intermediary researcher, with over 20 years of applicable experience. The intermediary researcher improved descriptive validity by serving as the third independent data evaluator and by mitigating potential biases through critique of data interpretations. Details of the roles of both coders and the intermediary researcher are provided in the methods section. Another triangulation strategy used is *theoretical triangulation*. Theoretical triangulation is described by Johnson (1997) as finding support for your interpretations and conclusions within theoretical literature. Data were first assessed based on the theories (e.g. CTT and data/frame theory of sensemaking) and research reviewed within this thesis. As data were analyzed, further literature review was conducted and discussed with the

intermediary researcher in order to critique interpretations of the data and provide support for proposed conclusions.

Second, *interpretive validity* can be described as the accurate portrayal of the participants' interpretations; that is, of their viewpoints, thoughts, intentions, and experiences. To this end, findings of this study are based on raw data transcribed verbatim and not summaries of the data. All conclusions presented in this research report are supported with raw data such as quotes from professors' and students' interview transcriptions, so that readers can judge the interpretive validity of those conclusions. In addition, participant feedback and peer review were used to assess the interpretive validity of reported results (Johnson, 1997). To receive participant feedback, results were presented to the ATC professors in order to obtain their assessments of the researchers' conclusions. To improve interpretive validity, peer review was solicited from the three thesis committee members. The committee regarded the researchers' results and conclusions with a degree of skepticism in order to challenge and provide insights that helped ensure the final results and conclusions were plausible, valid, and defensible.

Lastly, *theoretical validity* reflects the degree to which existing theory is consistent with research findings. The present research was essentially an exercise in theoretical validity as a function of assessing CTT and the data/frame theory of sensemaking. Strategies used for improving theoretical validity included field work, peer review, and pattern matching (Johnson, 1997). Field work consisted of observations of general classroom practices of the ATCT course. Peer review, as described above, served to improve both interpretive and theoretical validity. Pattern matching was used in the data analysis process where data were assessed and categorized into themes through coding. Codes were developed using a top-down and bottom up process

such that top-down codes (e.g. based on CTT and sensemaking theory) were attuned to embody emergent patterns in the data.

## **Research Objectives**

This is a naturalistic study with the following primary objectives:

1. Gain insight into the course framework used for introducing novices to the complex cognitive work domain of ATC. In addition, compare professor intentions with student perceptions in an attempt to gauge the relative value of the instructional strategies which comprise the course framework.
2. Assess ways in which both expert ATC instructors teach and ATC novices learn complex cognitive material in order to determine if there is (a) any support for recommendations of CTT, (b) any implications that suggest refinements to the theory, and (c) concrete instructional strategies that can serve as instantiations of CTT.
3. Advance applications of CTT for training and educational systems that can serve as a notional attempt to facilitate the acquisition of adaptive expertise in cognitive work domains.

## **Method**

### **Participants**

Two professors teaching a visual flight rules (VFR) air traffic control tower (ATCT) course in Embry Riddle's Air Traffic Management program voluntarily participated in this study. An experience questionnaire (see Appendix A) was given to the professors to elicit further information regarding their experience as controllers and professors of ATC. Results from the experience questionnaire are shown below in Table 1. Based on their experience, both professors can be considered experts and leaders within their domain. In order to continually improve their

effectiveness as instructors, both professors are recreational pilots; Professor 1 is active within Embry-Riddle's Center for Teaching and Learning Excellence, and Professor 2 is part of the FAA Flight Standards District Office flight safety team. Professor 2 was also a finalist for Embry-Riddle's 2012 Outstanding Teacher Award. A total of seven undergraduate students, four from Professor 1's tower course and three from a section of the same course taught by Professor 2, voluntarily participated in this study. The students' ages ranged from 19 to 21 ( $M = 20.14$ ,  $SD = 0.69$ ). The students' number of years in college ranged from 2.5 to 4 ( $M = 3$ ,  $SD = 0.5$ ).

Table 1

*Experience Questionnaire Results*

	Total ATC Years	Years Teaching Professional Controllers	Years Teaching as Professor	Number of Classes Taught Per Year
Professor 1	27	10	5.25	10
Professor 2	24	22	4.50	9

Each participant signed an informed consent and an audio data collection permission form (see Appendices B, C, & D). All participants were treated in accordance with the "Ethical Principles of Psychologist and Code of Conduct" of the American Psychological Association. All student participants were compensated \$10 for participating in the knowledge elicitation session of the study.

**Materials**

Two Sony IC Digital Recorders, model ICD - PX312, were used to record course observations and knowledge elicitation sessions. PowerPoint presentations for each of the examined topics were presented on an HP Mini 210-2080NR netbook during discussion of the corresponding topic in the knowledge elicitation session.



## Procedure

Data collection focused on observing and eliciting strategies for teaching and learning the three related flight separation tasks over three instructional phases. More specifically, the ATC tasks same-runway separation, wake turbulence separation, and IFR separation were studied across introductory, practice, and assessment phases. The procedure for data collection included course observations and knowledge elicitation sessions. Both procedures are described as follows.

**Course observations.** Both professors' courses were observed during the in-class introduction to each of the three ATC separation tasks, subsequent practice sessions, and during one performance assessment. Course observations were audio recorded and written notes supplemented the recordings. Course observations were used to guide and inform subsequent data collection and interpretation. The course observations also served as a *field work strategy*, which Johnson (1997) claims helps to improve theoretical validity by verifying that participants' transcriptions are in accordance with observed events.

**Professor knowledge elicitation.** A semi-structured interview protocol (see Appendix E) was conducted with each professor to capture the professors' verbal account of the strategies used to teach each of the three tasks over the one month period. Each professor was separately asked to walk through the month's instructional activities and to give detailed accounts grounded in specific examples. Artifacts were used to deepen the professors' explanations; these consisted of course schedules, syllabi, observation notes, and presentation slides. Knowledge elicitation sessions with professors were conducted individually in an office setting and were audio recorded.

**Student knowledge elicitation.** A semi-structured interview protocol (see Appendix F) was used to capture students' verbal accounts of the instructional activities they experienced during the same one month period described by the professors. Artifacts were used to deepen the students' explanations; these consisted of presentation slides, the course schedule, and syllabus, and observation notes. The artifacts were also used to help students recall specific memories of course activities and avoid generalizations. Knowledge elicitation sessions were conducted in a private conference room or an empty classroom and were audio recorded.

### **Data Analysis**

All knowledge elicitation sessions were transcribed from audio to text. Data records and audio files were labeled using participant numbers and dates. Audio was additionally labeled by stating participant numbers and the date at the beginning of each session. Transcripts of knowledge elicitation sessions were broken into data elements, where the content of any given data element is able to stand alone as a meaningful expression but does not contain more than one idea or concept. A total of nine transcriptions (attained from two professors and seven students) were coded using codes derived from CTT and the data/frame theory of sensemaking.

Coding was used to identify robust patterns in the qualitative data and as a measure to improve theoretical validity through pattern matching between emergent patterns in the data with strategies recommended by CTT. Robust support for any particular code; for example, a code for the use of a particular learning strategy, will take the form of multiple data elements from multiple participants mapped to that code. Less robust support for a code, e.g., from fewer data elements, means its validity will be assessed by considering the context in which the code was applied, its emergence or support from other research or theory, and the goodness of the match between the data and the code (e.g. agreement between raters).

**Code development.** The preliminary set of codes (see Appendix G) were derived from strategies advocated by CTT and sensemaking theory. The code development process was iterative and employed the researcher triangulation strategy to improve descriptive validity. The primary coder and intermediary researcher coded half the data elements of one professor and one student transcript while simultaneously revising the codes. The code revisions emerged from both patterns within the data and recommendations put forth in the CTT and the data/frame theory of sensemaking. Proposed code revisions and coding examples were compared, discussed, and agreed upon by the primary coder and intermediary researcher. Then, the intermediary researcher and primary coders coded a portion of the second professor and second student transcript. Then, a second iteration of proposed code revisions and coding examples occurred and lead to the development of the revised codes (see Appendix H).

**Data coding.** After the proposed code revisions, the primary coder and the intermediary researcher met weekly throughout the six week coding process to compare and discuss the codes in order to further define codes and improve descriptive validity through critique of data interpretations. The secondary coder was trained for the coding process using a similar method to that used for code revision between the primary coder and intermediary researcher. First, to improve theoretical validity in terms of matching patterns in the data to theory, the secondary coder was familiarized with CTT, the data/frame theory of sensemaking, and the ATC course artifacts; further, the secondary coder was trained to use the revised codes. For the first set of transcriptions (One professor and one student), the secondary coder coded data elements one page at a time and then compared and discussed each data element with the primary coder. After the secondary coder went through the initial transcription set, the two coders worked

independently on each transcript. As new or revised codes emerged, previous transcripts were revisited and coded in accordance with the new or revised codes.

After two professor and three student transcriptions were coded, the interrater agreement was analyzed for each set of initial codes. (The method for interrater agreement analysis between coders is detailed in the section below.) Based on the initial interrater agreement analysis, codes used dissimilarly were discussed by the coders and the coders then assigned a reconciled code to data elements they had previously assigned different codes. The discussion of dissimilarly assigned codes and their reconciliation followed the coding of the next two student transcriptions and occurred again after the completion of the final two student transcriptions.

The final set of codes used for coding the professor and student data elements are listed in Appendix I. Values were added to these codes in order to assess the interrater reliability. To further explore the data in its original context, original transcriptions of the data (not broken into data elements) were assessed using NVivo 9 - qualitative data analysis software. In NVivo 9, data elements were assigned their reconciled code, assessed in the context of their original position within the transcription, and then grouped and assessed by code. Assessment of the data was a sensemaking exercise itself. In order to meet the objectives of this research, data were coded to identify and assess patterns that could be used to compare teaching and learning in the ATC course with sensemaking theories. Further, professor intentions and student perceptions of strategies and course components were grouped and assessed to characterize and gauge the value of the strategies used for both teaching and learning for complex cognitive work domains.

After data were coded and assessed, the findings and conclusions were evaluated by both the secondary coder and the intermediary researcher to improve descriptive and interpretive validity. Participant feedback was solicited from the two ATC professors by presenting them

both with the proposed findings and conclusions and receiving their critical feedback. Moreover, interpretive and theoretical validity was improved through peer review in the form of a comprehensive presentation of the literature review, methods, results, and conclusions of this research to a committee of three experienced researchers.

**Interrater reliability.** The percentage of the direct agreement and the interrater reliability for independent ratings and reconciled ratings of the two coders were calculated for each transcript as well as for all transcriptions combined. The interrater reliability was assessed using Cohen's kappa coefficient, where a value of 0.75 or higher is characterized as a substantial agreement level beyond that due to chance; any value between 0.40 and 0.75 is characterized as a fair to good level of agreement beyond that due to chance; and values below 0.40 are characterized as a poor level of agreement beyond that due to chance (Banerjee, Capozzoli, McSweeney, & Sinha. 1999).

## **Results and Discussion**

The percentage of direct agreement for initial independent coding of the data was 57% and the interrater reliability calculated using Cohen's kappa coefficient was .51. The initial percentage of direct agreement and initial kappa were also calculated for individual transcriptions and the results are shown in Table 2. The initial Cohen's kappa coefficients for each transcript ranged from .35 to .66. Based on criterion set forth by Banerjee et al. (1999), the initial coding would be characterized as a fair level of agreement beyond that due to chance. The percentage of direct agreement for reconciled coding of the data was 93% and the interrater reliability calculated using Cohen's kappa coefficient was .90. The reconciled percentage of direct agreement and reconciled kappa were also calculated for individual transcriptions and the results are shown in Table 2. The reconciled Cohen's kappa coefficients for each transcript

ranged from .83 to .97. Based on criterion set for by Banerjee et al. (1999), the reconciled coding would be characterized as a substantial level of agreement beyond that due to chance.

Table 2

*Results of Interrater Reliability Assessment*

Transcript	Initial Percent Direct Agreement	Initial Kappa	Reconciled Percent Direct Agreement	Reconciled Kappa
P1	.75	.66	.88	.83
P2	.46	.35	.93	.88
S1	.60	.49	.94	.92
S2	.42	.40	.97	.97
S3	.64	.60	.96	.94
S4	.45	.39	.89	.87
S5	.66	.57	.93	.92
S6	.57	.57	.93	.91
S7	.59	.53	.92	.90
All	.57	.51	.93	.90

The total number of data elements analyzed across a total of nine transcriptions was 627.

The total number of data elements initially rated dissimilarly was 270 and after reconciliations the number of data elements rated dissimilarly between the two coders was 47. Total data elements and coding differences for each individual transcription is shown in Table 3.

Table 3

*Total Data Elements and Dissimilar Coding Frequencies*

Transcript	Total Data Elements	Initial Number of Dissimilar Coding	Number of Non Agreement after Coding Reconciliation
P1	106	30	13
P2	106	57	7
S1	48	19	3
S2	65	38	2
S3	56	20	2
S4	64	36	7
S5	76	26	5
S6	45	19	3
S7	61	25	5
Total	627	270	47

In order to begin to characterize each code, Appendix J lists each of the final codes with a sample data element that was assigned to that code. The format of Appendix J is similar to the format used for coding the data elements. The total frequency with which each code was assigned, separated by coder for the initial coding and reconciled coding, is shown in Table 4. In Appendix K, each code is discussed in terms of theoretical justifications its use as well as the contexts in which each code was assigned.

Table 4

*Total Frequency of Code Use of Both Coders for Initial and Reconciled Coding*

*Note: C1 = Primary Coder; C2 = Secondary Coder*

Total Frequency of Code Use					
Code	Initial Coding C1	Initial Coding C2	Reconciled Coding C1	Reconciled Coding C2	Mean Reconciled Percentage
1	35	62	35	40	6%
2	216	143	209	194	32.1%
3	50	53	50	48	7.8%
4	63	58	63	60	9.8%
5	17	23	16	20	2.9%
6	20	15	20	21	3.3%
7	6	13	8	9	1.3%
8	5	2	5	4	0.7%
9	40	46	41	41	6.5%
10	19	18	20	24	3.5%
11	13	19	14	15	2.3%
12	4	6	5	4	0.7%
13	1	4	1	1	0.1%
14	44	51	42	43	6.8%
15	29	34	31	33	5.1%
16	10	16	11	12	1.8%
17	11	11	12	11	1.8%
18	9	10	9	9	1.4%
19	3	1	3	3	0.4%
20	32	42	32	35	5.3%

## Course Framework

In order to ground the findings from the coding and the implications inferred from patterns in the data, components of the course framework are first detailed. Throughout the description of the course framework, professors' intentions and student reported perceptions of the strategies and components are presented. In this course framework section, raw data is included in the form of direct quotes from participants to aid in improving the descriptive validity of this research. Further, the results discussed in the course framework sections are aligned with the first objective of this research. That is, to gain insight into and detail the course framework used for introducing novices to the complex cognitive work domain of ATC. The air traffic control tower (ATCT) course framework is broken into the following levels: Module level, block level, and overall course. The course framework is described accordingly.

**Module.** Course artifacts (e.g., course syllabi and schedule, PowerPoint files, and observation notes) and the knowledge elicitation data were analyzed to assess the course framework. The most basic level of the course was determined to be the *module*, which focuses on a specific topic that students are to learn. There were a total of 11 modules in this course. Figure 2 presents the components contained within each module; specifically, *self-study*, *class*, and *simulation*. Various instructional strategies and methods comprise each component of the module and are presented below according to their corresponding component.

The following quote from one of the students illustrates the components of the module: “We had online modules so we went over kind of a self-study to introduce the topic. Then we had an in-class lecture portion going over details of everything, how it all operates, how to use the same-runway separation. Then we went in and practiced pre-set up scenarios that dealt with



same-runway separation so that we could look at and see distances and how to use it, get practice with the idea of same-runway separation.”

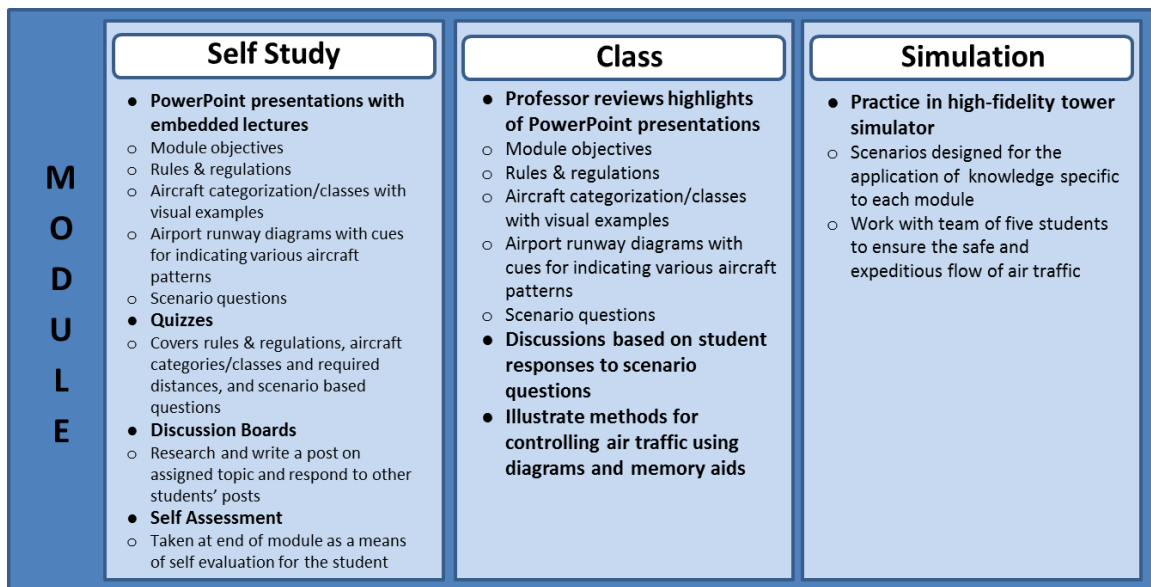


Figure 2. Model of course module.

**Self-study.** The self-study component of each module consisted of online PowerPoint presentations with embedded lectures, quizzes, discussions boards, and a self-assessment. It is important to note that the self-study component of each module represents the hybrid aspect of the course. Students were expected to complete the self-study component of each module prior to coming into class as illustrated by the following quote from one of the professors: “Well, we want the student to complete these online modules before we actually get into the classroom to do scenarios.” Five of the seven students echoed this expectation. For example, one student stated, “As they suggested, we first started online”; however, two students believed that the online self-study was to be completed at any time within the week that the topic was covered rather than prior to the first lecture on the topic. For example, one student stated, “The lecture was on a Monday, I believe, and then there was online activities for that week.”

*Online PowerPoint Lectures.* One of the professors stated, “Now [for] lectures what we use is PowerPoints with voice embedded macros. So the slides just automatically switch, they have our voice in there, so those are online for the students in each lecture. A student describing the PowerPoints stated, “It was a different slide for each [concept]. I know the technique that was given was one at a time, you know you hit enter and the next one would flash in, just so you could sort of see it. As it went further on and we got into the second or third one, you started to notice patterns and I think that was a big part of what it was. It was constantly 3,000, 4,500, and then 6,000 and for a couple there was [sic] deviations of that a little bit, but for the main part that was what it was. I think that seeing the pattern kind of helped [me] to learn really quick and then obviously practicing it straight after.”

*Quizzes.* The self-study component also included quizzes for students to take after going through the online lecture. One professor stated, “They take the quizzes and it is a way for them to self-evaluate themselves as to do they know the information or not.” One student stated, “We went through and did quizzes on different questions testing us on the things in the PowerPoints so the runway separation and the different criteria.” Another student stated, “When I took the quizzes, I always did it without notes the first couple of times and if I was struggling, then I might go and look at the notes.” Three students were unsure of the extent that quizzes benefited them; however, four students regarded the quizzes as beneficial. For example, one student stated, “We would take the quiz and think ‘Ok now I get it a little better, a better understanding of same-runway separation.’” Another student describes the quizzes: “It will basically be just a scenario quiz, where they will come up with real-life scenarios and say, ‘How much separation would you need here, here, and here?’ It was more a way to see it before you come to class, because the whole point is that you learn it yourself and kind of take it upon yourself to know it.”

*Discussion boards.* Discussion boards were not included in every module but they were considered part of the self-study portion of the course. One professor stated, “There could be an activity like, for instance, a discussion board, where we ask them to discuss with other students, or all the students in the class a variety of things.” Similarly, a student stated, “There was a couple of discussion board activities that we just did recently. They didn’t help anywhere near as much as everything else. It did help a little bit though because it made me look into the 7110.65. It was just a brief thing; you know, spend half an hour studying some things and then write your opinions on it.”

*Online self-assessment.* At the end of each module, students were given an online self-assessment that outlines what they should be able to recall at a given time during the course and what tasks they should know how to perform. Students did not refer to this self-assessment when asked about the online materials; however, the professor stated, “We tell the student at this point of the lecture at this point of the class you should be able to recall this, this, this, and that. We tell them where they should be. We actually gave them a skill check where they should actually be able to manipulate the aircraft this way or they should know this phraseology or whatnot. So that student progress I think can be important to a student so that they know they are getting feedback on how they do.”

*Class.* The class component of the module was observed to serve as a way for professors to reinforce and elaborate on the material students were provided during the online self-study component. When students first came into class, the professor was observed to give a brief lecture reviewing the highlights of the lectures they viewed online. The class began primarily as a review of the material presented online followed by scenario questions; these course components are discussed in the next two subsections.

*Review of self-study material.* One of the professors stated, “When they get to class, I review that information. I go over it again and I personally, using the white board, I will talk to them about how they can move airplanes and what separation they need for wake turbulence. So I am just reinforcing what hopefully they had online and maybe explaining slightly different than what was in the PowerPoints.” The other professor stated, “Now when we come into the classroom a lot of time we have a short little lecture that usually lasts five minutes, not very long and I will bring out the high points of those lectures that they just had online.” Similarly, one student stated, “So the more difficult the topics got the more we would start the class with the PowerPoint reviewing the PowerPoint, and then it was really just him rotating around the class [during practice] and maybe pointing something out.” And another student stated, “Then coming into class, the teacher would go over it, mostly on the board, with a little help from PowerPoint.”

*Scenario questions.* In this course, scenario questions provided students with various cues that characterize an air traffic control event including the aircraft types, locations on the runway, and other factors such that students are able to tie knowledge learned through other means to real-world dynamics and situations. In class, both professors were observed to use scenario questions as a strategy for reinforcing a topic covered in the self-study and also the cues that are important in a given scenario. Scenario questions were also observed to serve as a way to assess if students understand the material and for the professor to identify and correct any misconceptions. The following quote describes how the professors use scenario questions in class: “It is like a story problem. If you recall [scenario questions] were about two or three sentences and I would point out to them ... I’d say, ‘Look what’s important in this question?’ The question is that it is two smalls, or it is a small and a large... at the approach end of the runway. So we are trying to almost educate them on how to read that question, but the fact of the

matter is that it teaches them wake turbulence too. First we give them the information on wake turbulence, and then we kind of test them in the classroom, [through scenario questions to determine] are they even understanding this?”

Five of seven students viewed the in-class scenario questions as a review of the quiz they took online. For example, a student stated, “When we got in class it was more of a review of those quizzes and the material we had already looked at.” Three of seven students described using knowledge from the scenario questions in the simulation scenarios. For example, a student stated, “Then when you are up there doing the scenarios, it makes it a lot easier because you already know, or you have already done some of these scenarios before without you knowing. You’ve done it; you just don’t remember doing it. I think that just sort of translates, you don’t really need to think about it so much.”

***Simulation.*** The simulation component of the module is where students are provided the opportunity to use the high-fidelity tower simulator and begin to apply and test the accuracy of the knowledge they have gained. The simulators were observed to be used during in-class time and supervised by both the professor and lab assistants as well as out of class during required practice hours, where supervision is only by lab assistants. The following quotes from the professors illustrate the use of the simulation: “Once they have that information [from the online modules]..., then we actually will bring up scenarios where through simulation we will recreate situations where they have got to apply that separation.” The other professor stated, “Then when they get into the actual high-fidelity simulation, we start putting it all together because if you think about the hierarchy of learning, as you move up onto actually doing, it is a little bit harder than just the simple identification. So that is really where they are learning this course is once they get to that simulation.”

Each of the students described the simulation labs and particularly practicing with simulation scenarios as being the most beneficial part of the course. For example, a student stated, “Definitely the labs, the simulations; definitely, there is nothing, nothing that compares to it. You are actually working it, you’re doing it, you’re incorporating everything you have learned and you are just shoveling it all into one thing.” Another student describes how the simulation was more beneficial than the online learning component: “I’m personally a visual learner so just studying like online or in a book would not help me as much. I might really get to know the concepts and understanding the definitions of what this is or the definition of what that is and when to do it. Like I could learn and read through and know, ‘Hey, do this when you have this type of aircraft at this time or whatever.’ But when you actually have everything jumbled together and you are actually controlling the scenario, I just feel that that is a better learning experience. Whether you just jumped into it and are trying it out or if you already know the concept and you are trying it out that way, I think either way you are going to learn better.”

**Block.** The next level of the course framework, referred to by the professors as a *block* (see Figure 3), is composed of a series of modules, each focused on a specific topic, and followed by two assessment methods: a *block test* and a *performance verification*. In this course there are three blocks and within each block there was a minimum of three modules. The modules follow the format described above. The two assessment methods in the block are the ones that account for a greater percentage of the students’ overall grade in the course. More specifically, the students overall grade was accounted for by the following: performance verifications = 45% , block test account = 30%, quizzes = 20%, and online activities = 5%. These percentages represent the selective pressures that shape the priorities students developed and the activities in which they engaged.

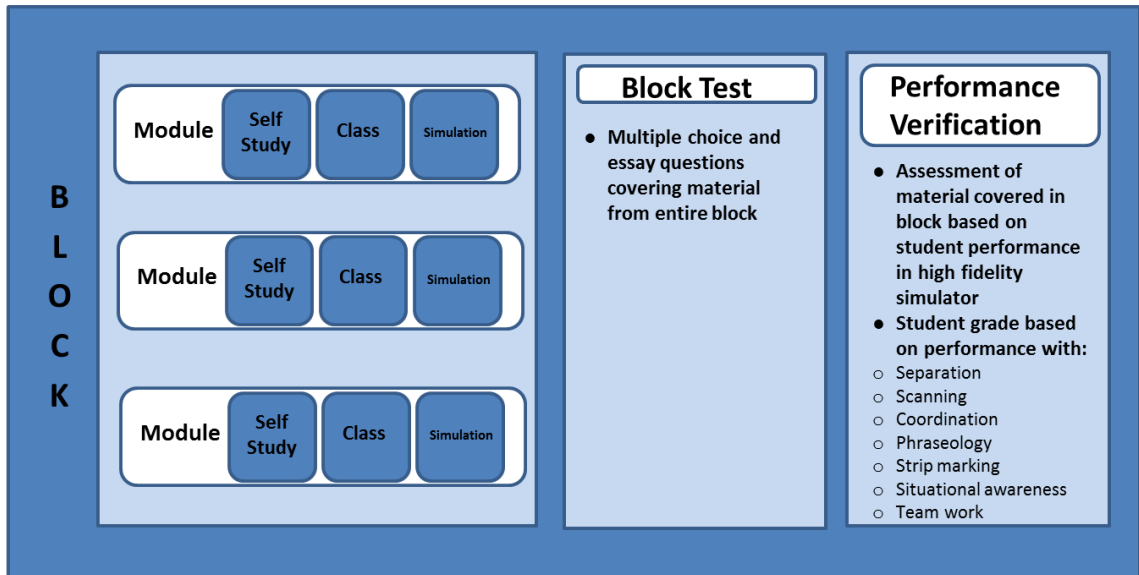


Figure 3. Model of course block.

**Block test.** The first assessment method, the block test, is similar to a typical exam found in an undergraduate course. The emphasis of the block test is on getting students to recall the information that was covered in all the modules of the block. For example, a quote from one of the professors describes the block test: “Where it comes down to it is a block test, which is written, where we ask them just like [in] a traditional class where you have lecture and then get tested on the material. It would be multiple choice or essay question, that type of thing.”

**Performance verification.** For the performance verification, students are evaluated on their ability to actually apply the ATCT material they have learned throughout the course. For example, one professor stated, “Then we have a performance verification, we call it, which is really set up just like the FAA has set up for their students going to the academy. Then we assess them during performance verification. We have a clipboard and we have a checklist of a variety of things that we do. So what we are looking for is separation, scanning, coordination, phraseology, strip marking, situational awareness, traffic movement, team work. Those are the

key factors we are looking for from each student during a performance verification. We give them a plus if they are doing exceptionally well in that area. We give them a minus if they are not doing so well. We comment on both plusses and minuses and then after the performance verifications we sit down with the students and we tell them where improvements should be made or where they are doing exceptionally well. Then that is part of their grade and as a matter of fact their last performance appraisal is really worth a significant amount of their grade. So the class is weighted heavily towards performing not towards filling in the right answers on a test; so it is actually doing and the students know that.”

The students’ accounts of the performance verification were very similar to that of the professors’. For example, when one student was asked to describe how their professor assessed students’ performance he stated, “Through performance verifications; having certain scenarios that we would run through that were set up to test the different topics that we covered. Going around having certain criteria that we’re graded on; whether we kept aircraft separated, had the proper phraseology, and were using the airport the most efficient way that we could. Then he would go through and watch our performance individually, make notes, and then review it with us so that he could critique and tell us what we could improve on and what we did well.”

**Course.** The overall course framework consisted of a total of three blocks (see Figure 4). In reference to the modules covered in each block, one professor stated, “Each one builds on the previous one until in the end, in the final week or two, they have finally started putting it all together and realizing the building blocks have built up to the point where they are really moving the traffic quite well.” Each module serves as scaffolding on which the next module builds and the information from each module and each block is continually applied in simulation scenarios



across the remainder of the course; each module and block adds and integrates an additional level of complexity.

The following quote from one professor characterizes the overall course: “The first [block] is pretty much rote learning. You have a lot of memorization. It’s not learning the skill as much, but when you get to same-runway separation, wake turbulence, and the IFR separation [i.e., the second block], they have to go a little more in depth into understanding the separation standards involved. It is not just rote learning. In other words, in this class they are using simulation, a high-fidelity simulation, and all the things they need to know for this were previously taken care of [in the first block].” This quote describes the professors’ levels of learning for the different blocks in the course. To further illustrate, the other professor stated, “The learning in block one concentrates on the most basic and lowest levels of learning; remembering, understanding, and applying knowledge in the simulations. As the course progresses [i.e., block 3], the students are expected to be able to analyze and evaluate air traffic situations and then to properly react to them while in the simulations.” Figure 4 depicts the levels of learning as described by both professors and shows how the professors intend for the first two blocks to target the three lower levels of learning; whereas, the third and final block targets the three higher levels of learning.

The levels of learning described by the professors depict the progressive development of ATCT knowledge and integration of ATCT knowledge within the context of simulation scenarios. It is important to make the comparison between the professors’ levels of learning and Blooms’ taxonomy of learning in the cognitive domain (Bloom, Englehart, Furst, Hill & Kratwohl, 1956; as cited by Smith & Ragan, 1999). The professors’ levels of learning were recall, understand, apply, analyze, evaluate, and properly react; whereas, Bloom’s taxonomy

describes the levels as recall, comprehension, application, analysis, synthesis, and evaluation. The two are similar; however, the professors' levels of learning do not contain the *synthesis* level, which Klein and Baxter (2006) describe to be most similar to sensemaking.

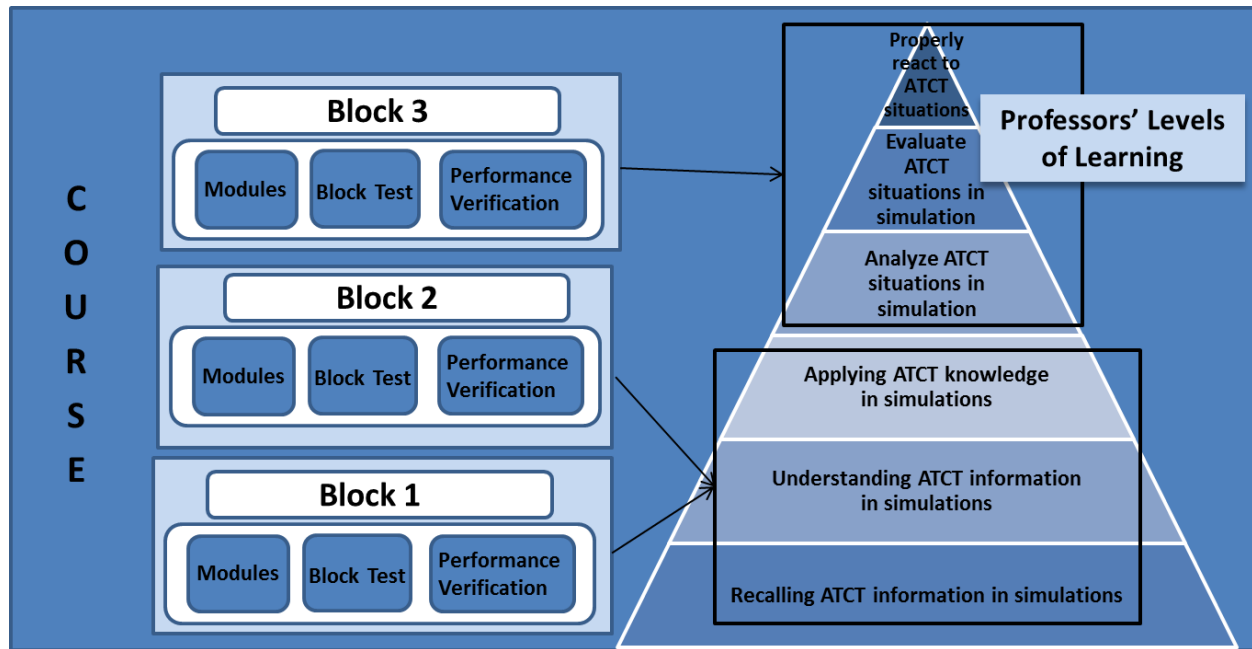


Figure 4. Framework of overall course and levels of learning.

**Value of strategies and course components.** This section addresses the second part of the first research objective, that is, to compare professor intentions with student perceptions in attempt to gauge the relative value of the instructional strategies which comprise the course framework. Professor intentions and students' reported perceptions of the instructional strategies and course components are presented. To this end, sources of frustration that students encountered while learning the types of aircraft separation were identified. Also, course components and instructional strategies that students perceived as beneficial to their learning were identified. Throughout this section raw data are used to improve the descriptive and interpretive validity of the findings and to reduce researcher bias.

***Wake turbulence frustrations.*** Wake turbulence was identified by both professors as the most difficult topic covered in the course and accordingly, this was the only aspect of the course that students recalled being frustrated with while learning. Responses from six of seven students suggested a common difficulty recognizing and identifying the type of aircraft and using that information to recall and apply the appropriate separation rule in the wake turbulence simulation scenarios. For example, a student stated, “Yea I was definitely frustrated because you think that you know it and it’s all well and good to study beforehand and memorize it, but then once you are actually working the local position, and now you have planes coming at you and people talking to you constantly. That’s when you are really put on the spot and you have to recall things really fast. You have to know what type of aircraft is landing and how heavy it is, what category it is.” Another student stated, “Trying to remember the rules for the different aircraft would get frustrating and mixing them up and landing aircraft or taking them off when they weren’t really supposed to be.” To further illustrate the students’ frustrations, another student stated, “I was mad at myself that I couldn’t understand the difference between a two minute roll from full length and a three minute rotation from an intersection and knowing what type aircraft was what. You need to know if it’s a large, a heavy, or a small and I wasn’t really familiar with what type of aircraft was what. So knowing where they go and the times, it just got frustrating.”

The professors described wake turbulence as the most complex topic and were aware that it was a major source of frustration for students. One of the professors stated, “Wake turbulence is the hardest block. It always has been and it will be in the future. There are just a lot of different scenarios to apply wake turbulence to.” In order to mitigate this learning frustration, the professors place a greater emphasis on this module. The course schedule specifies that the professors spend approximately two weeks on the wake turbulence module and a week or less on

all other modules. Accordingly, the three modules adhered to the schedule. One professor describes his approach for the wake turbulence module as follows, “So we go over those [wake turbulence] rules many, many times; I probably go over those [many times] because wake turbulence is a little more involved; as far as, the rules aren’t quite as clear cut as they are in same-runway separation. So often times it takes students longer to pick up the nuances and the finer point of wake turbulence.” The other professor describes practice with simulation scenarios as the key component that helps students learn this complex topic, “It is the application though, I am convinced, the way we have it set up. The application is really where it drives it home as to what the concept [wake turbulence] is that we are trying to teach them.”

***Beneficial strategies and components.*** Students perceived many of the components of the course to be beneficial to their learning. A quote from one of the professors on what he believes makes the course work was similar to comments from the students: “This is all that makes the class work: the practice session, the peer pressure with the group of five working together as a team, the online component versus what we use in the high fidelity simulation...those are all the main factors on what makes the course work.” Similar to this comment from the professor, students considered the online materials, practice with simulation scenarios, varying combinations of strategies and course components, and team interactions as the course strategies and components that were most beneficial to their learning. Student perceptions of learning value for the strategies and components described by the professors as “what makes this course work” are detailed in the subsections below.

***Online materials.*** Three of seven students mentioned that having the material available online and learning it prior to coming into class was beneficial, especially in terms of being able to use the knowledge during practice with simulation scenarios. For example, one student stated,

“It helped out having an idea going into class of what we were going to be doing and looking over it and knowing how to use the different rules and then when we get into class we are not just wasting time with the scenario. We kind of have an idea of what we are doing. It helps out to see it and see how different things work together so we have a better idea of what those rules are.” Another student stated, “I really memorized things ahead of time and tried really hard to do that. So that way my practice just helped me out that much more.” From both the professor and student perspectives, the self-study online component of the course seemed to be a valuable instructional strategy for preparing students to practice with simulation scenarios.

*Practice with simulation scenarios.* Each student mentioned that practicing in the high-fidelity simulation lab was beneficial to learning. Primarily, students perceived being able to actually see the concepts of the domain rather than just reading about them as a useful instructional strategy. For example, one student stated, “You could know that you need 3,000 feet but you don’t know what that looks like in real life. So I think the simulation is actually what helps you learn the most.” Another student stated, “I think, for me, just practicing it and seeing the different aircraft, kind of, once I got used to what it looked like, knowing where they are supposed to be and how they are supposed to be spaced, helped out a lot.” Similarly, a different student stated, “I think it is much easier to recall that information and be able to use it again after being in simulators and using the information, working with people, seeing how scenarios actually work, and how we actually apply these rules rather than just seeing it on a PowerPoint and trying to think of how we would use it.” More specifically, one student described how beneficial his interactions with the professor were while practicing with simulation scenarios: “What I think was most helpful was when we actually got into the labs and the teachers would have us try to do stuff that we both knew wouldn’t work. Just to see why it wouldn’t work and

then you could ease just out to the point where you are just at the most efficient you can be where it is still working and still being safe.”

*Course component combinations.* Four of seven students indicated that a combination of course components were beneficial to their learning in the course. For example, one student stated, “I think that having the combination of learning the rules online, then having an experienced teacher with the labs is probably a really good way to learn the material. I thought that their stories helped to back that up, because they would have stories of things that could have gone bad or that did go bad and it just helps you catch the warnings signs for the future.” Another student stated, “So I think it builds on top of each other, the one methods , the online, gets it in your head, and lab gets you to be able to regurgitate it a lot better than what it would just be online.” A different student describes how the various course components helped her learn the material: “Like I said having the material there helps. I just look over it like a bunch of times and doing it in class, sometimes I need help from an instructor to repeat or clarify it, but really for me it is just looking at the PowerPoint, going over it a few times, going to class, trying that, if it doesn’t work, getting help, and maybe getting them to clarify what they wanted.”

*Team interaction.* Similar to the professor describing that working in a group contributed to the courses’ success, six of seven students perceived team interaction as beneficial to their learning. For example, one student stated that what helped him learn was, “going through the scenarios in class and being able to watch as our whole team went through the scenario. So looking and controlling at a certain position but then being able to watch how everyone else was controlling it and handling things and watching them definitely helped out.” Not only watching other teammates but also interacting with them was described to be beneficial: “Being able to talk with my classmates about what problem we are working on. Hearing them say, ‘Oh you

need to do this' and I'd be able to say 'Why?' and they would explain it. Telling them 'Hey you need to do this' and then explaining it to them." Due to team interaction during practice, a student was able to learn how to differentiate who on his team needed help and as a result was able to improve his own knowledge; he stated, "I think practicing what helped [me] better was... tuning in to see who needs help and who doesn't and it helps you to become like a better controller to be able to help everyone around you and not just yourself. It's more just kind of perfecting what you already know."

Now that the course framework, sources of frustration, and the strategies and components of the course perceived as beneficial by students have been described, in the following section, The implications resulting from the combination of the coded patterns within the knowledge elicitation data, the strategies used by professors, and the components of the course will be discussed.

### **Implications from Coded Patterns, Strategies, and Components**

This section addresses the second objective of this research which was to assess ways in which both expert ATC instructors teach and ATC novices learn complex cognitive material in order to determine if there is (a) any support for recommendations of CTT, (b) any implications that suggest refinements to the theory, and (c) concrete instructional strategies that can serve as instantiations of CTT. Specifically, this section presents a comparison of the data with predictions CTT makes about learning in complex cognitive work domains. In the subsection that follows, findings and implications are presented that suggest there were phases to mental model development. In the subsections that follow, findings and implications are presented regarding the four components postulated to be requisite for learning in a cognitive work domain (e.g. diagnosis, learning objectives, practice, and feedback; Klein & Baxter, 2006) and essential

for facilitating increasingly accurate mental model development. This section concludes with a discussion of the codes not assigned to any data during the coding analysis with possible explanations for their lack of applicability, as well as a discussion of whether or not cognitive transformation can be said to have occurred in the course.

**Mental model development.** In CTT, the continual formation of increasingly accurate mental models is said to be essential for learning in a cognitive work domain. Three codes were assigned to characterize data regarding phases of mental model development. Of the three codes, the first code, ‘Teach/learn elements of mental model,’ accounted for 6% of all coded data, was assigned to data from eight participants, and yet was the least assigned of the three mental model development codes. The second code, ‘Form rudimentary mental model,’ accounted for 32.1% of all coded data, was assigned to data from all nine participants, and was the most prevalent of all codes. The third code ‘Develop fluency in use of mental model,’ accounted for 7.8% of all coded data and was assigned to data from seven participants. The relationship between the rather limited use of ‘Teach/learn elements of a mental model’ code with the most frequently assigned code ‘Form rudimentary mental model’ warrants further discussion and will be the focus of this section; whereas the code ‘Develop fluency in use of mental model’ is further discussed in the subsequent ‘Practice that incorporates sensemaking’ section.

The contrast in assignment of the former two mental model codes was likely due to both the nature of the material and the integrated way it was presented to students. Chi (2008) posits that the categorical assignment of concepts is an essential learning strategy in terms of forming mental models and this seemed to be inherent to the instructional strategies used for the ATCT students. Early in the course, students were taught aircraft types and as they moved into the complex separation tasks, aircraft types were assigned *categories* and *classes* depending on



which separation rule was being taught. These assigned categories and classes governed the way that types of aircraft were to be separated in terms of the amount of distance and time required between aircraft types and also was dependent upon their runway locations.

The data suggest the material in this course was mainly presented to students in a format that integrated different forms of knowledge and thus contributes to explaining the prevalence of the code 'Form rudimentary mental model.' As discussed in the course framework section, students' self-study of the material, beginning with the online PowerPoint presentations, was presented in such a way as to represent and help facilitate the integration of multiple forms of knowledge. Students were presented with not only the required rules and regulations, but also visual examples of aircraft types organized into their categories and classes, airport diagrams with directional and locational cues for moving aircraft, and scenario questions that provided context for moving various combinations of aircraft categories and classes from varying runway locations.

The practice of supporting mental model development is exemplified by the integrative diagrammatic presentation of the material in this course. Figure 5 shows a presentation slide that integrates text and diagram to convey temporal and directional cues. The presentation of the material was consistent with Fiore et al.'s (2003) findings that participants in training conditions that include a diagrammatic presentation of materials are able to interconnect information to form more robust knowledge structures (i.e. mental models) when compared to participants that did not receive training intervention. Knowledge structures in their study were considered robust when the connections formed between critical concepts, measured with a mental model assessment technique, were more similar to those of an expert. The presentation of material is also congruent with the findings of Lewandosky, Dunn, Kirsner, and Randall (1997) suggesting

that trainees presented with a diagram that integrated the forces influencing bush fires' varying conditions were able to gain a more complex understanding and demonstrated better performance on a simulated brushfire task when compared to trainees did not receive such an intervention. Table 5 presents categories of instructional strategies that support mental model development and then gives specific examples of ways each strategy type was implemented.

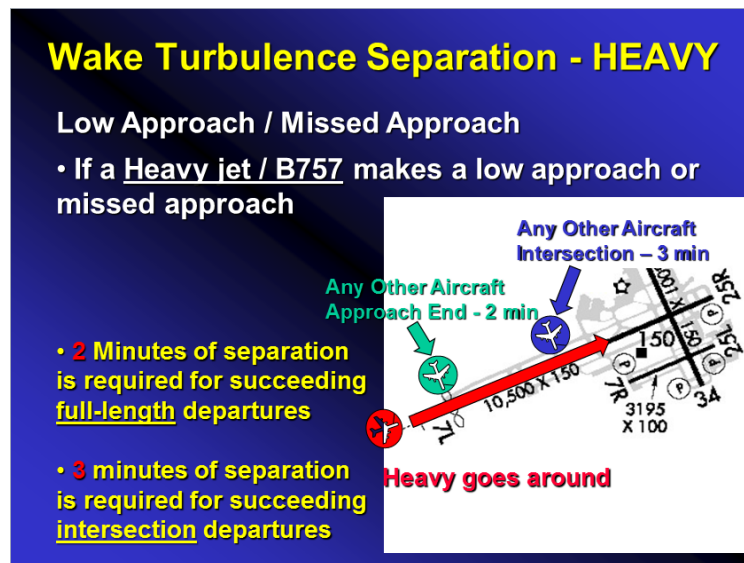


Figure 5. PowerPoint presentation slide used in self-study portion of the ATCT course.

Table 5

*Instructional Strategies Used that Supported Mental Model Development*

Categories of Instructional Strategies Used	Specific Examples of the Instructional Strategies Used
<b>Teach/learn elements of mental model</b> (6% of data elements)	Presented some concepts individually before integrating and providing context
<b>Form rudimentary mental model</b> (32.1% of data elements)	Taught aircraft categories and classes to help students distinguish aircraft and the associated separation rules Presented most material in integrated and diagrammatic forms including contexts
<b>Develop fluency in use of mental model</b> (7.8% of data elements)	Provided opportunities to use simulators both in class and during required out of class practice hours (see 'Practice that incorporates sensemaking' section.)

**Diagnostic assessments to identify flaws in mental models.** In CTT and other research on the acquisition of complex knowledge (e.g. Chi, 2008; Ericsson et al., 1993; Feltovich et al., 1993; Klein & Baxter, 2006), a diagnostic component that allows for the opportunity to identify flaws is essential. Again, in this research a flaw can be any type of mental model weakness or misconception. In this section, the types of assessments that were included within the course that contributed to the identification of flaws are presented. Then, the implications from two codes that accounted for the identification of flaws in students mental models are discussed. The first code ‘Reveal/recognize weakness in mental model,’ accounted for 9.8% of all coded data, was assigned to data from all participants, and was the second most prevalent code. The next code ‘Anticipate weakness in mental model,’ accounted for 2.9% of all coded data and was a strategy used primarily by the professors as they were primed to identify weaknesses they had come to expect teaching the material over time.

Based on course artifacts and knowledge elicitation data, six types of assessments were identified in the course that tested the students’ knowledge and helped them to identify flaws in their mental models. The assessment types, described as helping students identify flaws on their own, included: online scenario questions, online quizzes, and online self-assessments. To illustrate the notion that students identified weaknesses during assessments, a student stated the following, “When I took the quizzes, I always did it without notes the first couple of times and if I was struggling, then I might go and look at the notes.” The assessment types described as helping both professors and students identify flaws in mental models included: In class scenario questions, block tests, and performance verifications. The following quote describes how the professor was able to identify weaknesses during the performance verifications and address the most common weaknesses to the entire class: “Once we had our performance verifications...

[The professor] now knows how everyone is doing. Then, the next time we would come to class, he could address what most people had a problem with; how to correct it and what to do from now on.”

In addition to the explicit assessment types, the data suggest that mental model weaknesses were recognized by the professor and lab assistants and revealed to the student during the simulation component. For example, a professor stated, “Then they are going to apply it [in simulation scenarios] and we see that they really didn’t understand it.” Similarly, a student stated, “I think even if you just had the simulators, you still wouldn’t be as good because you could still get [aircraft] going but you’d probably be making the same mistakes over and over.” Klein and Baxter (2008) posit that virtual environments, such as the ATCT simulator used in this course, provide students with the opportunity to see how their actions play out, thus allowing the flaws in mental models to be revealed in a way that leads to richer mental models. Therefore, an implication for incorporating the practice of diagnosis is providing students with the opportunity to apply their knowledge in simulation scenarios with supervision and guidance from more experienced individuals, which in this course, was a means for identifying flaws in students’ mental models. Further, the data lends support for the benefit of simulation for student and instructor diagnosis as claimed in CTT.

Another finding was that students were able to recognize and reveal weaknesses in their teammates’ mental models. For example, a student stated, “The whole point of working together is that you can catch other peoples’ mistakes.” In this course, students were encouraged to work together and help out their teammates and as detailed previously, viewed team interaction as beneficial. Thus, another implication for the practice of diagnosis is that, in this course, even

when unsupervised by the professor and lab assistants, students have the opportunity to mutually diagnose and identify flaws in each others' mental models.

These findings not only support the first learning component advocated for by CTT – diagnosis – as useful for learning in a cognitive work domain; they also serve as instantiations of ways that diagnosis can be incorporated. Flaws in mental models were identified using different types of assessment strategies to determine the accuracy of students' knowledge and their ability to perform during simulation scenarios using that knowledge. The use of multiple assessment strategies, as recommended by Feltovich et al. (1993), meant there were multiple opportunities for weaknesses to present themselves; whether during online or simulation activities. Further, students were able to mutually diagnose and identify weakness in the mental models of their teammates. The identification of flaws in students' mental models allows for correction and revision such that, as Redding et al. (1991) suggested, over time students' mental models more closely approximate that of an expert. In sum, Table 6 presents categories of instructional strategies that support diagnosis and were identified in the data and then gives specific examples of ways each strategy type was implemented.

Table 6

*Instructional Strategies Used that Supported Diagnosis*

<b>Categories of Instructional Strategies Used</b>	<b>Specific Examples of the Instructional Strategies Used</b>
<b>Reveal/recognize weakness in mental model</b> (9.8% of data elements)	Include online scenario questions, online quizzes, online self-assessments, in-class scenario questions, block tests, and performance verifications Encourage peer evaluation during team simulation events
<b>Anticipate weakness in mental model</b> (2.9% of data elements)	Develop experience to more easily recognize weaknesses based on trending difficulties students face in the course

**Learning objectives that emphasize sensemaking and encourage reflection.** CTT

advocates that students should engage in a deliberate and continual restructuring of their mental models. In support of this goal, CTT suggests that students reflect on new information and its relationship with prior knowledge—i.e., on ways to integrate new information with the existing mental model. The use of reflection in the ATCT course was captured by the code, ‘Metacognitive: self-reflection, self-evaluation’ accounted for 3.3% of coded data and was assigned to data elements from seven participants. The code ‘Weave new learning into existing knowledge; connect new information to existing knowledge’ accounted for 1.3% of the data elements and was assigned to data elements from five participants. Thus, there was some evidence of instructional and learning strategies that involved reflection and the integration of new information with prior knowledge.

The code ‘Metacognitive: self-reflection, self-evaluation’ provided support for the usefulness of self-reflection during learning in a complex domain and there was evidence for prompting that encouraged metacognitive activities (see Table 7 for examples). However, encouraging reflection may not encompass all the cognitive learning activities that contribute to the development of increasingly accurate mental models. The data also contained evidence suggesting a role for prompting that elicits metacognitive processes. This finding is consistent with Fiore and Vogel-Walcutt (2010) assertion that metacognitive prompts, such as those used during observations of ATCT simulation practice, can facilitate *self-regulation*, which can be defined as “the ability to monitor and modulate cognition, emotion, and behavior, to accomplish one’s goal and/or to adapt to the cognitive and social demands of specific situations” (Berger, Kofman, Livneh, and Henik, 2007, p. 257). Specific to learning, Fiore and Vogel-Walcutt assert that self-regulation refers to assessing one’s learning not only through reflection (post-learning)

but also through preparation (pre-learning) and execution (monitoring learning as it occurs). An implication for the practice of encouraging sensemaking may be including metacognitive prompting that supports preparation and execution, as well as reflection. This strategy may be useful for the ATCT course as well as other educational systems such that, as proposed by Fiore and Vogel-Walcutt (2010), the overall length of training may be reduced.

The code ‘Weave new learning into existing knowledge; connect new information to existing knowledge’ represented a learning activity that was recommended by CTT and was indicative of reflection on new learning. CTT advocates that the connection of new information to existing knowledge should be encouraged through learning objectives; however, there were no specific objectives to facilitate this learning activity yet it was evident in the data. For example, one student stated, “The first thing we learned was same-runway separation and then they added wake turbulence. We learned that and it’s like a refinement, [where] you’ve added another level of sophistication to the rules.” Further, during each of the three observed class periods, professors recounted material from the preceding class and related it to the topic of the day by describing various scenarios and, thus facilitating the connection of new information with existing knowledge.

An assessment of the course learning objectives suggested there were no learning objectives clearly in accordance with recommendations of CTT. The following learning objectives are examples that were directly addressed during the observed portions of the course:

- Apply separation between arriving and departing aircraft in accordance with FAA Handbook 7110.65.
- Define wake turbulence, its effects, the factors affecting its intensity, and determine the appropriate wake turbulence separation in given situations.

- Define Category I, II, and III aircraft in accordance with FAA Handbook 7110.65 and determine applicable arrival and departure separation standards between categories.

The learning objective below was not specific to the observed portions of the course; however, it was an objective for the overall course and seems to be calling for students to develop sensemaking capabilities that serve them broadly within the ATC domain:

- Interpret data from multiple sources to reach a conclusion on a topic about ATCT

A follow-up discussion with the professors regarding this objective revealed that, “The intent [of the objective] was the student would be put in air traffic situations through [simulation] scenarios then, using visual and auditory senses, observe and interpret the events to formulate a response or action appropriate for the situation.” This description is similar to Klein et al.’s (2006a) definition of sensemaking; that is, to understand connections amongst data, information, or between events in order to predict outcomes and adapt performance based on those predictions. Though there were no objectives that clearly promoted sensemaking, there seem to be sensemaking elements in the learning objectives that may not have been explicitly emphasized in the course.

The data suggest that objectives were largely dismissed by students in this course. For example, one professor stated, “If [students] would read the learning objectives a little closer... they would probably pick up [the material] a little quicker... [Students] graze over learning objectives.” It is also worth noting that there no students referred to learning objectives during the knowledge elicitation sessions. This is problematic because the professors viewed learning objectives as important. That is, “learning objectives can tell a student what to expect in the



lecture” and the professors stated that they have their “learning objectives set up for what they are lecturing on” and that they will “test students based on that.”

Based on observations of the course, the inclusion of course learning objectives that map to professor intentions similar to the sensemaking definition (see above), and evidence in the knowledge elicitation data; sensemaking seems to be encouraged in this course and recommendations of CTT are indeed reflected in the instructional strategies used. Though there were no explicit learning objectives targeting student reflection, the incorporation of reflection on performance with simulation scenarios combined with instances where students were prompted to reflect and integrate new information with preexisting knowledge suggests that reflection is useful. However, an implication for the practice of encouraging sensemaking would include a more deliberate emphasis on reflection and, more broadly, self-regulation strategies. For example, a set of specific metacognitive prompts could be developed for professors and lab assistants to ensure that students form richer and more accurate mental models. Other implications these findings hold for CTT regard the necessity of learning objectives that explicitly encourage sensemaking and, for example, target student reflection and other diagnosis strategies advocated by CTT. Overall, the strategies used in the course that encouraged sensemaking but were not specifically written as formal objectives may be as central to student learning as the goals included in formal objectives. Table 7 presents categories of instructional strategies that support the encouragement of sensemaking and then gives specific examples of those strategies found in the data.

Table 7

*Instructional Strategies Used that Encouraged Sensemaking*

Categories of Instructional Strategies Used	Specific Examples of the Instructional Strategies Used
<b>Metacognitive: self-reflection, self-evaluation</b> (3.3% of data elements)	Prompt students with questions like: What can you do better? Why did you do this? What's important in this question? Is that 3,000 feet? Did it work? Now do you have the necessary 3,000 feet?
<b>Connect new information to existing knowledge</b> (1.3% of data elements)	Preface new lessons with a review of the preceding material and its relationship with the new material.

**Practice that incorporates sensemaking.** CTT advocates that practice is essential for helping students gain proficiency within a domain; however, practice alone is inadequate in cognitive work domains if it does not support the development of increasingly accurate mental models. Klein and Baxter (2006) propose that there needs to be an emphasis on providing students with ample opportunities to practice that incorporate sensemaking. Three codes were used to represent the practice learning component. The first code, 'Emphasis on performing or application of knowledge' suggested that the course was largely based on performance. The second code, 'Develop fluency in use of mental model' suggested that as students practice, certain aspects of performance became more automatic. Lastly, the third code, 'Assist/improve the directing and shifting of attention' provided support for attention management advocated by CTT.

The code 'Emphasis on performing or application of knowledge' accounted for 5.1% of all coded data and was assigned to data from seven participants, which indicated that both the professors and five of the seven students emphasized being able to perform or practice in the simulation scenarios as essential to learning in the ATCT course. For example, a professor stated, "It is the application [of knowledge] though, I am convinced, the way we have it set up.

The application is really where it drives it home as to what the concept is that we are trying to teach them.” Similarly, students indicated that being able to practice with simulation scenarios helped them learn. For example, a student stated, “In this class, it makes you have to actually learn it because you have to use it.” Another student stated, “I would memorize it and because we practice so often and I used that, I could say I kept that knowledge fairly well.” In the ATCT course, the emphasis on practice is similar to the repetition aspect of deliberate practice (see Ericsson et al., 1993); however, practice in the course was more similar to how Simon and Chase (1973) describe developing expertise in chess. That is, expertise is developed through practice through which an individual builds up a vast repertoire of patterns in long term memory such that patterns become easily recognizable and performance becomes seemingly automatic. Further, this buildup of perceptual patterns in long term memory is similar to Klein and Baxter’s (2006) notion in CTT that pattern recognition is essential for expertise in cognitive work.

The data suggested that as students practiced, the amount of thinking required for a given performance was reduced. The context in which the code ‘Develop fluency in use of mental model’ (see description in Appendix K) was assigned suggests that as students practiced, their performance became more automatic in two ways: recognition of stimuli (e.g., aircraft types) and recognition of patterns (e.g., combinations of aircraft types with their locations on the runway and the associated separation requirements). The following quotes describe the process in which recognition of stimuli becomes more automatic. A professor said, “You learn it to where you don’t have to think too much about it” and a student stated, “You basically learn your types of aircraft and when you see that aircraft you automatically think ‘that’s a heavy.’ The way you learn it is just practicing it.” The following quote from a student describes the way practice helps recognition of patterns become more automatic: “You get used to seeing planes at an intersection

that are going to wait three minutes if they are this size. You just kind of come to recognize, ‘ok he is this size and he is at this intersection, 3 minutes’. So you can just kind of look at it.” From the course observations and patterns within the data, it seemed that as students gained more experience through practice they were able to more easily recognize patterns of aircraft and the associated separation rules such that performance required less cognitive effort and became more automatic.

The code ‘Assist/improve the directing and shifting of attention’ accounted for 3.5% of all coded data and was assigned to data from five participants. Consistent with recommendations of CTT, professors and lab assistants helped students manage their attention during practice such that meaningful cues were recognized and cause-effect relations were noticed allowing students to form stronger causal relationships. For example, one student stated, “If you don’t see two planes hitting, you are not going to know they are hitting unless someone points it out to you or it draws your attention to it.” Similarly, a professor stated, “They start seeing their labs assistants and their professors pointing out to them that aircraft should be lining up to be out there on the runway. You should be clearing him for take-off already. You can clear him to land because you have this separation.” In the ATCT course, it seemed that practice incorporated sensemaking when professors and lab assistants provided students with procedural instructions, told students what tasks to attend to, and what cues are important.

In order to develop both deeper and more flexible knowledge, the professors used a strategy that was similar to the recommendation of Feltovich et al. (1993), Fowlkes et al. (2009), and Schwartz and Bransford (1998) that students be presented with cases in the form of scenario questions and simulation scenarios. The cases were coupled with lectures and the professors pointed out what was important in the scenarios; however, the majority of observed scenarios

were not explicitly contrasted with other scenarios. That is, professors did not pull up two scenarios at the same time and point out the differences. The emphasis was instead on providing as many cases as possible. However, it is worth noting that professor and student dialogue were used to contrast several tough cases, particularly for wake turbulence, with scenarios that featured other separation rules prior to practice in the simulation. Thus, the strategies used may represent an instantiation of how practice can incorporate sensemaking.

The data lent support for CTT in that practice was emphasized and strategies that support mental model development were employed. Students were provided the opportunity to practice in class and were required to complete a minimum number of practice hours outside of class. Whether in or out of class, both students and professors viewed practice as the most essential component of the course. In addition, student learning was enhanced by the use of strategies that gave them experience recognizing the cues and patterns that matter. Comparing and contrasting cases was not advocated by CTT; however, it may be an additional strategy to support the increasingly accurate development of mental models and thus there is opportunity for the strategies in the course to be improved. This strategy could be improved primarily in the sense that if comparing and contrasting cases was made more deliberate by professors, students may recognize cues and patterns more readily. Table 8 presents categories of instructional strategies that support sensemaking practice and then gives specific examples of those strategies found in the data.

Table 8

*Instructional Strategies Used that Supported Sensemaking Practice*

<b>Categories of Instructional Strategies Used</b>	<b>Specific Examples of the Instructional Strategies Used</b>
<b>Emphasis on performing or applying knowledge</b> (5.1% of data elements)	Devote large portion of class time to practice with simulation scenarios Base large percentage of grade on performance in simulations scenarios
<b>Assist/improve the directing and shifting of attention</b> (3.5% of data elements)	Present students with complex cases and explicitly point out the cues that matter as well as compare and contrast them with other cases through lecture and discussion
<b>Develop fluency in use of mental model</b> (7.8% of data elements)	Practice with simulation scenarios so that stimuli and patterns become easier to recognize and performance becomes more automatic

**Feedback that indicates how performance can be improved and prompts sensemaking.** CTT asserts that feedback should inform students of how performance can be improved and encourage students to seek and interpret feedback on their own. That is, students should be encouraged to employ sensemaking in order to learn causal relationships. There were seven codes directly pertaining to feedback and they accounted for a sum total of 20.6% of all coded data; however, only the two most frequently assigned codes, ‘Give/receive process feedback: simulation, professor, lab assistant, team’ and ‘Supplement inadequate mental model; seek or provide information about what student should be doing,’ are discussed in this section (see Appendix K for details about other codes).

The code ‘Give/receive process feedback: simulation, professor, lab assistant, team’ accounted for 6.8% of all coded data, was the most prevalent of the feedback codes, and was assigned to data from all nine participants. The prevalence of process feedback across all participants is consistent with recommendations of the data/frame theory of sensemaking, CTT,

and Blickensderfer et al. (1997). Specifically, for cognitive work, it is more important to know how performance can be improved (i.e., process feedback) than to just know that the performance was wrong (i.e., outcome feedback). This principle of feedback was reflected in the types of feedback given in the ATCT course. For example, the code ‘Give/receive outcome feedback simulation: professor, lab assistant, team’ was only assigned to characterize a single data element and thus, simply knowing that performance was wrong did not tend to be viewed as beneficial as knowing how performance could be improved.

Though CTT advocates the use of process feedback, it also proposes that limits be placed on the extent to which feedback is given by external sources. The authors assert that this limitation is needed so that students learn to seek and interpret feedback on their own, a capability that will allow them to continue learning and improving long after they complete their formal training. In comparison, professors and assistants provided ATCT students with robust external feedback that gradually decreased as the course progressed and student performance improved. For example, a professor stated, “As the days go by, our input diminishes to the point where at the end of the semester, theoretically, we shouldn’t be saying anything to the students; we are just watching them run the airplanes. I mean they should be applying all those little inputs that we gave along the way. You know, giving them feedback as they went.” An implication for CTT is that students provided with robust initial feedback, that is decreased as they advance in the course, may still develop the capability to seek feedback on their own.

The code ‘Supplement inadequate mental model; seek or provide information about what student should be doing’ accounted for 6.5% of all coded data, was the second most prevalent feedback code, and was assigned to data from all nine participants. This code accounted primarily for instances in which students recognized a weakness in their mental model and then

sought the information from their teammates, lab assistants, or professor. This code was also assigned to describe the use of memory aids. For example, one student referred to “having the cheat sheet and applying it in practice” as something that helped him become more efficient at applying the separation rules. The frequency of this form of support within the data is consistent with the postulate of CTT that as novel events unfold, students are able to construct more accurate mental models by seeking the information on a just-in-time basis. Moreover, just-in-time feedback strengthens the perceived relationships between causes and effects and thus enriches students’ mental models (e.g., Klein & Baxter, 2006). Students in the class were provided robust initial process feedback that decreased as the course progressed and students demonstrated in simulation scenarios that they knew the material; however, when students were presented novel scenarios they were observed to recognize their limitations and seek the feedback or information necessary to achieve fluid performance.

The data indicated that one source of just-in-time information, regarded as beneficial by both students and professors, was other students. The professors strove to create a cooperative and team-oriented environment that approximated teamwork in real-world ATC operations. One professor said, “You want them to be able to talk back and forth between each other and point out maybe where someone didn’t do something quite properly or correct without the feeling of being slighted.” Similarly, a student stated, “What helps me learn the best or what has helped me? Being able to talk with my classmates about what problem we are working on. Hearing them say ‘Oh you need to do this’ and I’d be able to say ‘why’ and they would explain it; telling them ‘hey you need to do this’ and then explaining it to them.”

As students recognized weaknesses in their mental model by means of practice, diagnostic strategies, and feedback, they drew upon a robust support system consisting of



teammates, lab assistants, professors, and memory aids. This seemed to help ensure that students were able to understand causal relationships as they occur. The robust support system in this course allows for students to form and revise their mental models through recognition of cause and effect relationships, flaws in their mental models, and strategies to improve performance and is something contrary to CTT. Students have the opportunity to see their actions play out in the simulator and when they are unsure of the proper action to take, there are numerous sources of information they are able to use to supplement their mental models and continue performing. In sum, Table 9 presents categories of instructional strategies that support process feedback and then gives specific examples of those strategies found in the data.

Table 9

*Instructional Strategies Used that Provided Process Feedback*

<b>Categories of Instructional Strategies Used</b>	<b>Specific Examples of the Instructional Strategies Used</b>
<b>Give/receive process feedback</b> (6.8% of data elements)	Provide frequent process feedback during initial learning and decrease process feedback over time so student learns to seek and interpret feedback on their own
<b>Supplement inadequate mental model</b> (6.5% of data elements)	Make multiple sources of process feedback available just-in-time to ensure fluid performance during simulation exercises.

**Unassigned codes.** Two codes derived from CTT were not assigned to any of the data elements. The first unassigned code, ‘Discard and replace mental model; significantly revise mental model,’ was to meant to characterize data elements that represented the types of knowledge shifts that could be characterized as cognitive transformation. Also, this code would have captured instances of significant unlearning. All students indicated they were unfamiliar with the material before it was covered in the course and there was no evidence in the data to suggest large-scale unlearning occurred. However, students could have learned the material

inaccurately due to their own misinterpretation and then adjusted their understanding on a smaller-scale as flaws and weaknesses were detected.

The second unassigned code, ‘Protect mental model: explain away inconsistencies; distort data’ was based on one of the postulates of CTT. In CTT, mental model protection is a tendency people often demonstrate that interferes with mental model development and learning. Common mental model protection strategies include explaining away data and distorting data (see Klein & Baxter, 2006; Klein et al., 2006). An example of such a strategy is when an individual perceives data that is contrary to their current mental model and then finds some method for discrediting it rather than questioning the current mental model. Evidence of these and similar strategies was not found in the ATCT students. The students’ mental models may not have been sufficiently developed for a sense of protection to have taken hold. Respectively, the distortion of data is associated with individuals who have gained enough experience to develop stronger mental models and therefore, mental model protection may not have been evident due to students’ inexperience in the ATCT domain.

One explanation for why the two codes did not map to any of the data was likely due to the novice level of experience of those in the course as supported by students reported unfamiliarity with the material prior to each module. In CTT, Klein and Baxter (2006) argue that the concept of unlearning should be included in any cognitive learning regimen; however, in the observed course there was no direct evidence for unlearning. Even one of the professors stated, “We make sure that everything they learn in this course is accurate so that when they get to the [FAA] academy they won’t have to unlearn anything.” Based on the course observations and data collected, there was a robust system in place that facilitates the identifications of flaws in students’ mental models that allow for frequent revisions. This process seems more of an

attunement rather than an unlearning, where unlearning would be a large-scale shift in understanding versus the smaller-scale adjustments evident in the data.

An alternate explanation for the unassigned codes is that this study heavily relied on knowledge elicitation data and students may not have been inclined to describe or even able to recognize biases in their learning and further, the collection and assessment of the data may also have contributed to the lack of support for unlearning in the results. Nonetheless, unlearning may be invaluable at later stages of learning; however, when students are relatively new to a domain, as was the case with the ATCT course, an emphasis should be placed on ensuring that the complexities and foundations of the domain are perceptible through performance, so that flaws can be identified.

**Occurrence of cognitive transformation.** In CTT, cognitive transformation is a mental model development process that an individual undergoes as he or she learns new material (Klein & Baxter, 2006; Klein & Baxter 2008). That being said, the data seems to indicate that some form of cognitive transformation occurred during this course. This claim is based on a number of factors including the prevalence of codes suggesting phases to mental model development, the students' unfamiliarity with the material prior to its introduction, and the use of strategies that support recommendations of CTT. However, it is worth noting that cognitive transformation is a rather vague term in that, it seems there could be varying degrees to which it occurs. More specifically, this course seemed to indicate that there was more of a mental model attunement process; whereas, it is possible that certain types of learning could lead to a significant unlearning in which a mental model might be completely transformed or discarded. The operationalization of cognitive transformation is certainly an issue that would need to be examined in future research.

## **Applications of Cognitive Transformation Theory to Training and Educational Systems**

This section addresses the third research objective which was to advance applications of CTT for training and educational systems that can serve as a notional attempt to facilitate the acquisition of adaptive expertise in cognitive work domains. The ATCT course examined in this research represents an instantiation of the introduction to a complex cognitive work domain in which various instructional strategies (e.g. quizzes, tests, scenario questions, simulation scenarios, team interactions, etc.) are used in complementary ways to provide students with experience applying their knowledge in order to “explore, reflect, learn, work through confusion, and develop deeper and richer mental models while carrying out complex tasks” (Crandall et al., 2006, p. 214). This ATCT course may represent a critical period in student development which lays the foundation for future development and performance. More specifically, during this period students are able to develop sensemaking strategies they may use to develop expertise as they progress through the various educational systems associated with ATC (e.g., university, FAA academy, on-the-job training, etc.).

In order to gain expertise in cognitive work domains (e.g., ATC), Klein and Baxter (2008) assert that there are several forms of knowledge students must develop. These include: declarative knowledge, routines and procedures, recognition of familiar patterns, perceptual discrimination skills, and, most importantly, increasingly accurate mental models. Based on limitations of today’s dominant training strategies (see Hoffman et al. 2009; Klein & Baxter, 2006), CTT focuses on providing recommendations for developing the latter three knowledge forms. In the present study, the development of all five forms of knowledge was observed to occur through the instructional strategies selected for the ATCT course. This provided support

for the essentiality of the five forms of knowledge for acquiring expertise in a complex cognitive work domain.

Throughout this thesis, theory and research encompassing instructional, training, teaching, and learning strategies have been discussed and thus, the entirety of strategies referenced in this research may be applicable to both training and educational systems. This section presents applications of CTT that are supported by this research and relevant literature. This section represents a notional attempt to recommend strategies that may support the acquisition of expertise that is well suited for cognitive work domains. The applications are organized under the four learning components of CTT (i.e., diagnosis, learning objectives, practice, and feedback) that contribute to the acquisition of continual learning strategies required to develop adaptive expertise in cognitive work domains.

This research revealed four strategies for implementing the diagnostic learning component of CTT. They are as follows:

*Include Multiple Diagnostic Assessments:* This study showed how diagnostic assessment of all five forms of knowledge (i.e., declarative, routines and procedures, recognition of familiar patterns, perceptual discrimination skills, and mental models) can be integrated into a three month college course. Consistent with the diagnosis claims of CTT, the ATCT course demonstrated a robust diagnostic system that included multiple methods for targeting these forms of knowledge through traditional assessments (e.g., quizzes and tests) and by providing students with opportunities to perform in challenging scenarios that simulate the real-world work. The inclusion of multiple diagnostic assessment methods is useful for identifying flaws and misconceptions (Feltovich et al., 1993); however, assessments should not only differentiate and target these five forms of

knowledge, but they should also test the integration of the forms of knowledge (e.g., mental model assessments).

*Improve Instructor Diagnosis:* This research supported the recommendation of CTT that instructors need to be able to identify commonly occurring flaws in mental models so that they can proactively detect and correct those misconceptions and the resultant performance inaccuracies (Feltovich et al., 1993; Klein & Baxter, 2006). This study suggests that instructors should actively seek, identify, and document the cues and patterns in student performance that signify flaws or misconceptions in order to anticipate and reduce the cognitive effort required for diagnosis. This should allow instructors to adjust their strategies to mitigate misconceptions and, as a result, more students would benefit as the instructor's efforts can be directed towards other interactions.

*Prompt Team Diagnosis:* As recommended by CTT and supported in this research, students ultimately need to be able to diagnose and identify flaws on their own. The present research suggested that an effective diagnostic strategy for students was identifying flaws and weaknesses in the mental models of teammates. This may have been beneficial to students as it has potential to facilitate the diagnostic capabilities for assessing one's own mental model such that an 'adaptive mindset' can be developed. Further research could investigate whether the mutual diagnosis occurring between teammates contributes to self-diagnosis capabilities.

*Challenge Students' Understanding:* A core premise of CTT is that the diagnosis of flaws and misconceptions facilitates the continual revision of students' and practitioners' mental models so that they increasingly approximate that of an expert. An effective strategy for revealing flaws and misconceptions is to directly challenge a student's understanding, which has been said to support them in recognizing ways they need to improve or adapt (Hoffman et al., 2009; Klein & Baxter, 2006). The use of this strategy was demonstrated

in the present research when simulation scenarios were used to provide students experience with tough cases that occurred infrequently in the real-world.

Many facets of the ATCT seemed to encourage sensemaking; however, the formal learning objectives component of CTT was not evident in the ATCT. Two alternative approaches to fostering sensemaking are as follows:

*Emphasize Instructional Strategies vs. Learning Objectives:* A refinement to CTT suggested by this research is that explicit learning objectives may not be necessary to encourage sensemaking. This is contrary to a core tenet of CTT. Rather, instructional strategies and technologies may adequately encourage sensemaking.

*Provide Metacognitive Prompting:* A refinement to CTT suggested by this research is that self-regulation strategies that engage a student in metacognitive activity prior to, during, and after a learning episode (see Fiore and Vogel-Walcutt, 2010), rather than just reflection on prior learning as proposed in CTT, may more closely approximate the sensemaking that is foundational for developing the type of ‘adaptive mindset’ essential for facilitating expertise in cognitive work domains (Klein & Baxter, 2006). An effective strategy for implementing self-regulation strategies would include the explicit use of metacognitive prompting to help facilitate sensemaking prior to, during, and after a learning episode.

*Require Integrative Self-Study:* CTT claims that increasingly accurate mental models must be developed (Klein & Baxter, 2006). In the ATCT course, including an integrative self-study component prior to a lecture or practice session seemed to be a useful strategy for fostering mental model development. This may also be an effective strategy for preparing students to actually apply their knowledge and perform in simulation scenarios.

This research revealed four strategies for implementing CTT’s practice learning component. They are as follows:

*Provide ‘Real-World’ Practice:* Practice for cognitive work needs to closely approximate that of the real-world work in terms of the “job’s challenges, contexts, and duties” (Hoffman et al., 2009, p. 20) and careful consideration should be given to the type of practice to be implemented. This recommendation is consistent with a teaching strategy in the ATCT course, as the high-stakes nature of the ATC domain warrants the use of the high-fidelity ATCT simulation. The recommendation above is caveated with the admonition that, depending on the characteristics of the domain and the desired performance, different fidelities of simulations may be equally effective and sometimes multiple fidelities may be necessary (Klein & Baxter, 2006). The ATCT course demonstrated the use of not only used high-fidelity simulation, but also low-fidelity simulation taking the form of scenario questions that were worked through as a class.

*Manage Attention and Integrate New Material:* Deliberate practice over an extended length of time can lead to expertise (Ericsson, 1993); however, deliberate practice in combination with the recommendations of CTT and the strategies outlined in this section may reduce the amount of time required to facilitate adaptive expertise for complex cognitive work domains. To this end, a claim of CTT, supported by this research, is that students should gain experience performing tasks with an experienced instructor who assists with the directing and shifting of attention and the integration of new information with preexisting knowledge. In the ATCT course, one effective strategy to assist in the directing and shifting of attention is to point out important features of simulation scenarios that students are not attending. An effective strategy for integrating new information with preexisting knowledge in this course was to preface the introduction of new material with a review of prior relevant topics and discuss how the topics were interrelated. These strategies may contribute to reducing the time required to begin to recognize familiar patterns and develop perceptual discriminations skills and thus, warrant further examination.



*Provide Novel Scenarios:* CTT and supporting literature claim that in order to develop expertise in cognitive work domains, students need to be able to flexibly apply their knowledge to novel situations (e.g., Bransford et al., 1989; Hoffman et al., 2009; Klein & Baxter, 2006; Spiro et al., 2003). This claim is consistent with the instruction studied in this research. Specifically, an effective instructional strategy used in this course is to provide students with a variety of simulation scenarios and scenario questions, varying in complexity, which allows students to perform in situations they have no prior experience with.

*Provide Complex Cases:* In support of recommendations of CTT, an effective strategy used in the ATCT course is to allow students to gain experience working with complex cases (see Feltovich et al., 2003) that are explicitly compared and contrasted (see Fowlkes et al., 2009) and further explained in a lecture or discussion format (see Schwartz & Bransford, 2000).

This research revealed three strategies for implementing the feedback component of CTT. They are as follows:

*Gradually Decrease Reliance on Feedback:* CTT holds that process feedback is necessary for complex domains but that it should be used sparingly. In contrast, students in this study initially seemed to require extensive process feedback from external sources (e.g., instructor and lab assistant) that indicated to them how their performance could be improved. According to this research, a more effective strategy may be to gradually wean students from reliance on external feedback as they demonstrate their ability to apply their knowledge effectively.

*Provide Just-In-Time Information:* CTT claims that students to seek and interpret feedback on their own. Students in the ATCT course required numerous sources of feedback (e.g., teammates, instructors, simulation components, and memory aids) to be readily available. An effective strategy for implementing the feedback component of CTT is to ensure that

numerous sources of feedback are available to help ensure that just-in-time information is provided to students as soon as flaws or weaknesses in knowledge are recognized.

*Verify Understanding of Feedback:* Klein et al. (2007) assert that process feedback can be misunderstood in the absence of an accurate mental model. The strategies advanced in this section should help students in forming increasingly accurate mental models, which is said to be necessary for students to interpret and understand feedback (Klein & Baxter, 2006). A valuable strategy ATCT instructors used to ensure effectiveness of feedback was to check that the feedback was understood. They did so by coupling provisions of feedback with a short period of observation until the student executed a performance that indicated to the instructor that the feedback was understood.

**Generalizability of CTT strategies** Prior to describing the strengths and weaknesses of this research, is worth discussing the degree to which these applications may generalize to other instructional settings as well as other domains. It is difficult to say that these findings would generalize; however, the primary basis for making such a claim would be that CTT is a learning theory based on two decades of research examining experts and novices in various complex cognitive work domains. This section details prominent characteristics of the ATC domain, the instructors, and the students in attempt to make more explicit the conditions in which the applications may generalize.

First, ATC is a high-stakes domain that requires individuals to seek and interpret many sources of data under time-pressure when the stakes are high. As previously discussed, the ATCT course represents the introduction to a complex cognitive work domain and thus, it is expected that these strategies would be most generalizable during the introductory learning phase of a domain. As there was an explicit emphasis on the application of knowledge in the course, it is possible that other domains which share a similar emphasis may benefit from these

applications. More specifically, when the goal of the instruction is to help prepare students for performing in the real world, these strategies may be more beneficial. One example of this could actually be towards the field of human factors which is often an applied science. That is, human factors instructors may find some of these strategies useful because they should help prepare their students for performing in the real world in which they would have to seek and interpret varying amounts of data in order to help solve ill-defined problems and design complex systems. Also, though this research aims to help provide a way forward in training and education for complex cognitive work, the degree to which the strategies are useful for domains inherently less complex is a question that should be further examined.

Next, the instructors of this course are certainly above the norm. That is, they held outstanding performance records when they were professional controllers and they are constantly striving to provide their students with the best education possible. For these findings to be generalizable, instructors must be willing to put a continuous effort into seeking and interpreting causal relations and feedback for what does and does not work. More specifically, instructors must learn to form increasing accurate mental models so they can adapt their curriculum and instructional strategies accordingly and this research aims to help provide some strategies that help facilitate this.

Lastly, students in this course were highly engaged in that they put the effort into learning material prior to coming to class, applied the knowledge during class, and practiced in the simulation lab outside of class. Though there are certainly individual differences in students, the course design and instructors can largely influence student engagement. Nonetheless, if students are not willing to engage in a continuous learning process then these applications may not be generalizable for them. In sum, the domain, instructional setting, instructor, and students

comprise the variables which influence the degree to which the applications outlined in this section are generalizable. Future research should explore these issues in order to make supported claims for the generalizability of these findings.

### **Strengths and Limitations**

The use of naturalistic research methods in a real-world instructional setting is viewed as one of the strengths of this study. This allowed for the opportunity to explore the instructional strategies used to introduce novices to a complex cognitive work domain by individuals who were ATC domain experts and experts at teaching both professional and aspiring controllers. Some may suggest the naturalistic design of the study and inherent lack of control of the study environment is a limitation; however, it was chosen because of the rich qualitative insight into the intentions of professors and perceptions of students during the instruction of complex cognitive concepts. Though the coding and interpretation of qualitative data can be subjective, the data collection and assessment methods used helped to improve validity and mitigate biases. Knowledge elicited from participants may have been subject to reductionist distortions in individual recollections; however, course observations and the grounding of knowledge elicitation sessions with course artifacts were means to counter these distortions.

One limitation of this study is that the sample size was small; this was largely due to the amount of time it took both to collect and analyze the data as well as limited availability of ATC instructors who were considered experts. If data were derived from more than the two professors and seven students, the sheer quantity of qualitative data elicited could have been overwhelming. These professors were chosen to participate because of their ATC and instructional expertise as well as their novel use of a strategic instructional approach that they had developed and evolved over the prior five years. Other professors' strategies may have been more traditional and may

not have contributed as meaningfully to this research. Nonetheless, it is important to state that the course examined in this study represents the strategies used for a specific type of cognitive work for a specific domain. Thus, exploring the strategies in use for instruction in other complex cognitive work domains may also have implications for the theories and could add to the development of generalizable applications of CTT for training and educational systems.

Another limitation of this study is that due to the qualitative nature of the data, quantitative claims and claims of statistical significance cannot be made about the efficacy of the strategies employed in the course or the extent that they measurably improve performance when compared to conditions that did not employ such strategies. However, the current research was necessary for setting the stage for that type of research. Another important strength of the method is that they revealed multiple paths of future inquiry about the value of CTT and sensemaking theories as routes to developing expertise in cognitive work domains. As such, further research is warranted to begin to quantify the efficacy of the recommended strategies for applying these theories. Recommendations for this future research are discussed in the section below.

## **Future Research**

Based on the similarities between the strategies used in the ATCT course and those recommended by CTT and sensemaking theory, further research about the effects of applying these theories to facilitate the acquisition of expertise for cognitive work and more generally to training and educational systems seems warranted. In this section, a method that may be useful for measuring cognitive transformation is described; then, motivation to further explore the relationship between metacognition and sensemaking is presented; and lastly, recommendations for assessing if strategies derived from CTT and assessed in this research can actually accelerate the learning process are provided.

Feltovich et al. (1993) propose a tight coupling between cognitive research and educational systems such that cognitive developmental goals can be linked to educational methods. This type of approach is said to be useful for developing and implementing plans for the continual improvement of educational systems. Consistent with this vision, Nickles and Pritchett (2012) have proposed a cognitive systems engineering framework for designing and evaluating educational systems called a *work action analysis* (WAA). As the goal of an educational system is primarily student learning, the WAA framework provides a means to map course artifacts, physical and cognitive activities, roles, and system goals of an educational system so that the various interrelationships can be clearly understood.

Once mapped into the WAA framework, measures can be specified for designing and evaluating targeted components of the system in order to improve the system as a whole. The measures developed using a WAA can be used to examine, among other things, how students' cognitive performance evolves. This may be useful for identifying system aspects that support cognitive transformation as changes in cognitive performance can specifically be linked to various artifacts, physical and cognitive activities, and other elements of the educational system. The ATCT course, examined in this research, may be ideal for submitting to a WAA to further assess both the course framework and the instructional strategies consistent with recommendations of CTT. Data collected for this research can be used to begin to complete the WAA framework; however, further knowledge elicitation will be required to fully complete the framework, to determine what measures are already in use, and what measures need to be developed.

Though some researchers have reported difficulty assessing mental models (e.g., Cooke & Rowe, 1994), others have found mental model assessments beneficial for diagnosing and

predicting performance (Scielzo et al., 2002) as well for identifying conceptual changes within mental models (Chi, 2008). The type of mental model assessment that would be most beneficial for attempting to capture cognitive transformation over time warrants further research and would most likely vary for a given domain. A WAA framework may be useful for making this determination and identifying the appropriate method for implementing it.

The benefits of metacognitive prompting, as a strategy for encouraging self-regulation, warrant further study. Knowledge elicitation data collected for this study can be reassessed and coded to identify evidence for the three types of metacognitive prompts (e.g., planning, monitoring, and reflecting; see Fiore & Vogel-Walcutt, 2010). This would help to establish the relevance of self-regulation as opposed to just self-reflection for CTT and further support Fiore and Vogel-Walcutt's claims regarding the usefulness of metacognitive prompting.

The relationship between metacognition and sensemaking also warrant further study. There are many questions that could be asked about the relationship between metacognition and sensemaking. For example, how does metacognition benefit sensemaking and is metacognition a key component of sensemaking? Metacognition is defined as the process through which humans monitor and control their cognitive processes in an effort to identify flaws or opportunities for improvement and to adjust those cognitive processes accordingly (e.g., Bransford & Cocking, 2000; Ford et al., 1998; Redding, 1989). Sensemaking can be described as the intentional cognitive processes required to understand connections amongst information or between events in order to predict outcomes and adapt performance based on those predictions (e.g., Klein et al., 2006a; Klein et al., 2007). There seems to be some overlap between these two concepts and thus, the relationship between them should be further researched and clarified.

A final recommendation is to conduct research that assesses if the strategies recommended in CTT and extended through this research can actually accelerate the learning process. When one of the professors was asked what impact the introduction of the hybrid-elements into his course had on learning, he said, “I think what I have done is probably accelerated the learning of students ... I think when I first got into it, the teaching of this particular course, I did not force so many skills on them, but now I have more skills that I expect them to know at the end of the course.” Measures developed using the WAA as well as traditional controlled laboratory research could be useful for establishing whether the instructional strategies in use in the ATCT course and the strategies recommended in this thesis can actually reduce the amount of time required to learn in a complex cognitive work domain such that expertise is gained. Controlled studies may not be able to incorporate and assess all aspects of the ATCT course (e.g., expert instructors); however, experimental training conditions could be designed to assess the effects of the instructional strategies recommended in this research.

### **Conclusion**

In sum, this exploratory research was instrumental for gaining insight into the instruction of novices in a complex cognitive work domain and for identifying strategies that support and refine claims of CTT. These strategies may be useful for facilitating the acquisition of adaptive expertise in students of a complex cognitive work domain and warrant further study. This research does not claim to have determined how best to facilitate the acquisition of adaptive expertise for cognitive work; rather, it serves as a starting point, an initial framework, on which to build, so that the recommendations of CTT can be applied to training and education systems.



The applications of CTT detailed in this research may have the potential to foster learning and continual development long after structured training and education commence. The sensemaking learning activities reviewed in this research (e.g., diagnosis, learning objectives, practice, and feedback) may allow an individual to continually refine and attune their knowledge such that the perceptions, motor responses, and decisions that define their interactions with the environment steadily become more fluent and flexible (e.g., Klein & Baxter, 2006; Klein et al., 2006b; Sieck et al., 2007).

In the following quote, Noam Chomsky (Learning Without Frontiers, 2012) describes his view of the purpose of education. There are connections with aspects of CTT and sensemaking theory, which could be characterized as a need for sensemaking strategies in education.

[The purpose of education should be] to help people determine how to learn on their own... You can't pursue any kind of inquiry without a relatively clear framework that's directing your search and helping you choose what's significant and what isn't... If you don't have some sort of a framework for what matters — always, of course, with the provisor that you're willing to question it if it seems to be going in the wrong direction — if you don't have that, exploring the internet is just picking out the random factoids that don't mean anything... You have to know how to evaluate, interpret, and understand... The person who wins the Nobel Prize is not the person who read the most journal articles and took the most notes on them. It's the person who knew what to look for. And cultivating that capacity to seek what's significant, always willing to question whether you're on the right track — that's what education is going to be about, whether it's using computers and the internet, or pencil and paper, or books.

There are obvious connections between this quote and the theoretical and empirical work described in this thesis. The primary points made by this quote and CTT is that at any level of learning, whether it is for professional work or within the traditional education system, people need to learn how to learn on their own and in order to do so they must have a framework with which to determine what information to seek, when to seek that information, and when the information is irrelevant. Further, Chomsky and CTT propose that it is essential for an individual to continually question and regulate his or her learning and the resultant outcomes of learning on performance.

In conclusion, this research documented the effective employment of strategies that support many of the recommendations of CTT. Their employment by instructors who had no awareness of CTT or sensemaking theory, but who had to succeed in preparing students for complex cognitive work is in itself, testimony for the value of CTT and the need for its further application in training and educational systems.

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## Appendix A: ATC Professor Experience Questionnaire

**PARTICIPANT ID:** \_\_\_\_\_

**DATE:** \_\_\_\_\_

### EXPERIENCE QUESTIONNAIRE

The following questions (1-10) refer to your experience teaching in an operational work setting:

1. What education or training have you received on instruction/training or evaluation? Please list courses and activities:

2. How many years experience do you have as an Air Traffic Controller? \_\_\_\_\_ yrs

3. What is the highest level of facility at which you worked? \_\_\_\_\_

4. For how many years did you work in a facility of that level? \_\_\_\_\_ yrs

5. With what facility types do you have experience? Please indicate the number of years of experience working in each:

Tower only: \_\_\_\_\_ yrs

TRACON only: \_\_\_\_\_ yrs

Tower and TRACON: \_\_\_\_\_ yrs

ARTCC: \_\_\_\_\_ yrs

6. What is the highest position in which you worked?

☐ Certified Professional Controller

☐ Traffic Management Coordinator

☐ Staff Specialist

☐ Operational Supervisor/First-Level Supervisor

☐ Operational Manager/Second-Level Supervisor

☐ Manager/Assistant Manager

☐ Other (specify): \_\_\_\_\_



For how many years did you work in this position? \_\_\_\_\_ yrs

7. Approx. how many hours have you worked as a Training Instructor (OJT)? \_\_\_\_\_hours
8. Please identify any other indicators of air traffic control expertise or improvement such as awards, honors, invitations, recognitions, successes, etc.
9. How many months or years of experience do you have teaching professional Air Traffic Controllers?  
\_\_\_\_\_ yrs \_\_\_\_\_ mths
10. List positions and activities that involved the instruction or evaluation of professional Air Traffic Controllers:

The remaining questions refer to your experience teaching in an academic environment:

11. How many years of experience do you have teaching in an academic environment?  
\_\_\_\_\_ yrs \_\_\_\_\_mths
12. How many courses have you taught per year, on average? \_\_\_\_\_
13. Please identify your professional activities and hobbies that have the potential to improve your effectiveness as an instructor:
14. Of those activities, which do you do with the explicit goal of improving your effectiveness as an instructor (please circle the activities)?
15. Please identify any other indicators of teaching expertise or improvement, such as awards, honors, recognitions, invitations, student successes, etc.:

## Appendix B: Professor Consent Form

### PROFESSOR CONSENT FORM

I voluntarily consent to participate/collaborate in the research project entitled: **A Naturalistic Study of Instruction in a Complex Applied Domain**. My participation will involve teaching and evaluating students, over a one month period, as required in my course. Afterwards, my participation will involve reviewing the strategies used over the course of the month to teach three complex tasks. My answers to these questions will be used to gain insight into how people learn and make sense of information within a complex domain. This process will take approximately 60 minutes of my time.

The principal investigator of the study is **Mr. Travis Wiltshire**, a graduate student in the ERAU Human Factors and Systems Department. If I have questions about this study, I should contact Travis Wiltshire at 321-698-0270 or wiltshit@my.erau.edu. Further questions can be answered by contacting Dr. Neville at 386-226-4922 or nevillek@erau.edu.

I understand that the investigators believe that the risks or discomforts to me are as follows:

- *No greater than would be experienced in the everyday instructional environment of the AT 315HYB course.*

The benefits that I may expect from my participation in this study are minimal. I understand there is no guaranteed benefit; however, my participation in this study may offer opportunities to contribute to improved theory and guidance for teaching complex material.

My confidentiality during the study will be ensured by assigning me a coded identification number. My name will not be directly associated with any data. The confidentiality of the information related to my participation in this research will be ensured by maintaining records only coded by identification numbers. Video and photographic images of me will not be published or displayed without my specific written permission.

The individual above or a member of his research team has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation. Possible benefits of the study have been described.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that **I am free to withdraw consent at any time** and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: \_\_\_\_\_

Name (*please print*): \_\_\_\_\_  
(Participant)

Signed: \_\_\_\_\_  
(Participant)

Signed: \_\_\_\_\_  
(Researcher/Assistant)

## Appendix C: Student Consent Form

### STUDENT CONSENT FORM

I voluntarily consent to participate in the research project entitled: **A Naturalistic Study of Instruction in a Complex Applied Domain**. My participation will involve learning and performing air traffic control activities in as part of the requirements of my course, AT 315HYB, and reviewing and explaining comprehension and integration of learned material. This process will take approximately 60 minutes of my time.

The principal investigator of the study is **Mr. Travis Wiltshire**, a graduate student in the ERAU Human Factors and Systems Department. If I have questions about this study, I should contact Travis Wiltshire at 321-698-0270 or wiltshit@my.erau.edu. Further questions can be answered by contacting Dr. Neville at 386-226-4922 or nevillek@erau.edu.

I understand that the investigators believe that the risks or discomforts to me are as follows:

- *No greater than would be experienced in the everyday instructional environment of the AT 315HYB course.*

The benefit that I may expect from my participation in this study is \$10 at the end the interview. By participating in this study, I may contribute to improved theory and guidance for teaching complex material.

My confidentiality during the study will be ensured by assigning me a coded identification number. My name will not be directly associated with any data. The confidentiality of the information related to my participation in this research will be ensured by maintaining records only coded by identification numbers. Video and photographic images of me will not be published or displayed without my specific written permission.

The individual above or a member of his research team has explained the purpose of the study, the procedures to be followed, and the expected duration of my participation. Possible benefits of the study have been described.

I acknowledge that I have had the opportunity to obtain additional information regarding the study and that any questions I have raised have been answered to my full satisfaction. Furthermore, I understand that **I am free to withdraw consent at any time** and to discontinue participation in the study without prejudice to me.

Finally, I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: \_\_\_\_\_ Age \_\_\_\_\_

Name (please print): \_\_\_\_\_  
(Participant)

Signed: \_\_\_\_\_  
(Participant)

Signed: \_\_\_\_\_  
(Researcher/Assistant)

## Appendix D: Audio Data Collection Permission Form

### AUDIO DATA COLLECTION PERMISSION FORM

As part of this research project, you will be audio recorded during the interview that follows the simulation-based evaluation. We would like you to indicate what uses of these audio recordings you are willing to consent to by initialing below. You are free to initial any number of spaces from zero to all of the spaces, and your response will in no way affect your credit for participating. We will only use the audio recordings in ways that you agree to. In any use of these audio recordings, your name would *not* be identified. If you do not initial any of the spaces below, the audio recordings will be destroyed.

**The audio recordings can be studied by the research team for use in the research project.**

Please initial:

**The audio recordings can be studied by members of the research team for use in future related research projects.**

Please initial:

**The audio recordings can be shown at meetings of scientists interested in the study of cognition and learning in complex domains.**

Please initial:

**The audio recordings can be shown in classrooms to students.**

Please initial:

**The audio recordings can be shown in public presentations to nonscientific groups.**

Please initial:

### FOR QUESTIONS ABOUT THE STUDY

- Questions, Concerns, or Complaints: If you have any questions, concerns or complaints about this research study, its procedures, risks and benefits, or alternative courses of treatment, you should ask the principle investigator Travis Wiltshire. You may contact ask questions now or later at 321-698-0270 or wiltshit@my.erau.edu.
- Independent of the Research Team Contact: If you are not satisfied with the manner in which this study is being conducted, or if you have any concerns, complaints, or general questions about the research or your rights as a research study subject, please contact the Embry Riddle Aeronautical University Internal Review Board (IRB) to speak to an informed individual who is independent of the research team. The ERAU IRB point of contact is Dr. Albert Boquet (386-226-7035; albert.boquet@erau.edu).

**I have read the above description and give my consent for the use of the video and audio recordings as indicated above.**

Date: \_\_\_\_\_

Name (*please print*): \_\_\_\_\_  
(Participant)

Signed: \_\_\_\_\_  
(Participant)

Signed: \_\_\_\_\_  
(Researcher/Assistant)

## Appendix E: Professor Semi-Structured Interview Protocol

Participant ID: \_\_\_\_\_

Date: \_\_\_\_\_

Permission to audio record interview? Y / N

**Researcher Notes:** *To prepare for the protocol be sure to bring printed copies of all course artifacts and forms i.e. course schedule, syllabus, and informed consent. Ensure that the PowerPoint presentations used during the course are already pulled up on the computer prior to the beginning of the protocol. Keep the notes from the course observations readily available to ensure that probe questions can be used.*

First of all I would like to thank you for your participation. During this Retrospective Think Aloud Protocol, you will be asked to recall and discuss the strategies you used during the current semester of your ATC Tower course to teach each of the three elements of aircraft separation, e.g. same-runway separation, wake turbulence, and IFR separation.

Using the course schedule as guide, I'd like you to walk through the four weeks of your course starting on (October 5<sup>th</sup> or 6<sup>th</sup>), focusing on the three elements of aircraft separation and describing the instructional activities that took place both in and out of class. I would like for you to describe exactly what you did to teach the students each element of aircraft separation and what you expected the students to be learning along the way.

I would like you to, class by class or week by week, describe how you taught each of the separation rules starting with same-runway separation. Please describe your goals, activities, expectations, and student interactions from day to day as you taught this concept. Please try to describe what you recall actually teaching and doing and not what you planned to teach and do. I have powerpoint slides and notes from these classes and will be using them to try to help you remember the specifics.

Let's start with the first week in which you taught **same-runway separation**. *<Show slides and notes>*. During the first day or week, what do you recall doing or having students do, and why, in order to learn this separation rule?

**Researcher Note/Repeat Point:** *Wait while professor recounts what he recalls; after professor walks through and describes how they taught the separation rule and what they expected students to learn, go back to the beginning of their account ask them for more details as appropriate and also the following questions:*

- Can you recall examples of observing or noticing visible signs that students were “getting it” or otherwise benefitting from the strategies you used? If so, please describe what you noticed.
- Can you recall an example of a student or students experiencing difficulty with the material or rule? If so, can you describe the difficulty, how you noticed it, and how you responded?

Next, I would like you to, class by class or week by week, describe how you taught the **wake turbulence rule** *<Show slides and notes>*. What do you recall doing or having students do, and why, in order to learn this separation rule? *<Repeat above procedure from Repeat Point>*

Now, I would like you to, class by class or week by week, describe how you taught the **IFR separation rule** *<Show slides and notes>*. What do you recall doing or having students do, and why, in order to learn this separation rule? *<Repeat above procedure from Repeat Point >*

## Appendix F: Student Semi-Structured Interview Protocol

Participant ID: \_\_\_\_\_ Age: \_\_\_\_\_

Date: \_\_\_\_\_ Gender: \_\_\_\_\_ Years in college: \_\_\_\_\_

Permission to audio record interview? Y / N ← *This is here as a reminder to researcher to ask.*

**Researcher Notes:** *To prepare for the protocol be sure to bring printed copies of all course artifacts and forms i.e. course schedule, syllabus, and informed consent. Ensure that the PowerPoint presentations used during the course are already pulled up on the computer prior to the beginning of the protocol.*

First of all I would like to thank you for your participation. During this Retrospective Think Aloud Protocol, I would like you recall and discuss the strategies that your professor used that supported your comprehension and understanding of each of the three elements of aircraft separation, e.g. same-runway separation, wake turbulence, and IFR separation during your ATC Tower course. To describe how a concept was taught to you, I'm going to ask you to try to recall memories of class activities, e.g., lectures, quizzes, tests, and exercises and I'd like you to describe what you recall of them to the best of your ability.

Think back to the introduction of the concept same-runway separation (Approx October 5<sup>th</sup> or 6<sup>th</sup>). What can you recall about how this rule was taught? Please recount what you understood about it before it was introduced in class and what course activities or interactions helped you understand it better.

**Researcher Note:** *Show slides and wait while participant recounts Then, ask the following questions:*

- Did you notice at some point that the rule had become clearer or easier to understand and use? That you had become good at using the rule? If so, please describe the improvement in your understanding, what led to it, and how you noticed it.
- Do you recall being frustrated at any point while trying to learn the rule? If so, please describe what led to the frustration, how long it lasted, and what led to its reduction.
- Do you recall really understanding this rule or some aspect of it or its use? Please describe the material that you understood so well and how you learned it.

**Researcher Note:** *Walk back through response and ask elaboration questions (listed near end of protocol), pausing to let the interviewee elaborate or drill down further.*

Now, think back to your introduction to wake turbulence. What can you recall about how this rule was taught? Please recount what you understood about it before it was introduced in class and what course activities or interactions helped you understand it better.

**Researcher Note:** *Show slides and wait while participant recounts Then, ask the following questions:*

- Did you notice at some point that the rule had become clearer or easier to understand and use? That you had become good at using the rule? If so, please describe the improvement in your understanding, what led to it, and how you noticed it.
- Do you recall being frustrated at any point while trying to learn the rule? If so, please describe what led to the frustration, how long it lasted, and what led to its reduction.
- Do you recall really understanding this rule or some aspect of it or its use? Please describe the material that you understood so well and how you learned it.

**Researcher Note:** *Walk back through response and ask elaboration questions (listed near end of protocol), pausing to let the interviewee elaborate or drill down further.*



Now, think back to your introduction to IFR separation. What can you recall about how this rule was taught? Please recount what you understood about it before it was introduced in class and what course activities or interactions helped you understand it better.

**Researcher Note:** *Show slides and wait while participant recounts Then, ask the following questions:*

- Did you notice at some point that the rule had become clearer or easier to understand and use? That you had become good at using the rule? If so, please describe the improvement in your understanding, what led to it, and how you noticed it.
- Do you recall being frustrated at any point while trying to learn the rule? If so, please describe what led to the frustration, how long it lasted, and what led to its reduction.
- Do you recall really understanding this rule or some aspect of it or its use? Please describe the material that you understood so well and how you learned it.

**Researcher Note:** *Walk back through response and ask elaboration questions (listed near end of protocol), pausing to let the interviewee elaborate or drill down further.*

**Elaboration Questions:** *Walk through researcher notes of the interview from the beginning, of this concept asking the interviewee the following questions for aspects of the class, homework, etc. that was recalled (each aspect one at a time or a group of aspects together; whichever seems to work better.):*

- What did this help you learn?
- How did you observe that this helped you learn?
- What was new, interesting, or surprising about that/these?
- Did you notice that you understood something that you previously hadn't understood or hadn't recognized as important? What helped you gain that understanding?

- Did the material remind you of anything you were already familiar with?
- Was there anything about your understanding of separation that changed as result of learning this?
- Can you recall any interactions with your professor that allowed you to gain more information or improve your understanding? If so, please describe?

**Concluding Questions:** *Ask the participant the following questions:*

- Can you recall a specific class activity that you learned most from and why?
- Can you recall specific activities that engaged you to participate in the class?
- Can you recall what you observed your professor doing to ensure you understood the material during the course?
- What did you observe your professor doing to assess your performance?

## **Appendix G: Preliminary Codes for Data Analysis**

### **Cognitive Transformation Theory Codes**

#### **Strategies for Diagnosis**

- P1. Instructor is attempting to understand the student's understanding/mental model.
- P2. Instructor is attempting to understand a flaw/the source of a flaw in a student's understanding/mental model.
- P3. Instructor is providing opportunities to help student recognize and acknowledge misconceptions/inaccuracies in his/her mental model.
- P4. Instructor is providing opportunities to help student discover more useful and accurate mental model.

#### **Strategies for New Learning**

- P5. Instructor is helping student weave new learning into what he/she already understands.
- P6. Instructor is helping student form a new mental model.
- P7. The instructor is helping the trainee understand how actions and consequences are related and how to think about causal connections.
- P8. The instructor is helping the student learn how to direct and focus attention.

#### **Strategies to Foster Independent Learning**

- P9. The instructor is encouraging self-reflection.
- P10. The instructor is helping the learner develop self-evaluation skills.

## Appendix H: Revised Codes for Data Analysis

Redundant: Identical point was made previously and was coded.

Background: Interviewee is explaining something to the interviewer so that his/her words will make sense to the interviewer.

### Code 1: Course Component

Self-study

Class

Simulation

### Code 2: Sensemaking Support Use sub categories only when they are explicit

Teach/Learn individual **elements** of (future) mental model (Isolated from context of use?)

Knowledge (e.g., about categories)

Form **rudimentary** mental model:

- Knowledge of rules regulations, aircraft categories, airport diagrams
- Cause-effect relations (Scenarios) – Forming rudimentary cause-effect relations occurs when learners link causes to effects or learn cause-effect stories.
- Perceptual cues and patterns – Learning rudimentary perceptual cues and patterns involves the initial learning of which perceptual elements, cues, and changes matter.

Develop **fluency** in use of mental model

- Knowledge of ways to increase/improve performance or effectiveness
- Cause-effect relations – Knowledge about routine cause-effect relations becomes automatized. Connections become stronger and better developed to support faster and more complete recall of relevant mental model elements.
- Perceptual cues and patterns – Perceptual learning characterized by improved recognition of useful perceptual cues, patterns, and shifts. Recognition becomes faster and difficult or subtle perceptual details become easier to distinguish.

Reveal/Recognize **weaknesses** in mental model (inaccuracies, flaws, misconceptions, simplifications, gaps) (quizzing or testing could reveal weaknesses)

Knowledge (e.g., about categories)

Cause-effect relations

Perceptual cues and patterns

**Anticipate** weaknesses in mental model

Discard and replace mental model; Significantly revise mental model

Protect mental model: explain away inconsistencies; distort data

Encourage/Perform sensemaking activities (e.g., self-reflection, self-evaluation): Student seeks and interprets feedback on his/her own; sorts out what happened on his/her own.

- Weave new learning into existing knowledge; connect new information to existing knowledge.
- Assist with/Improve the directing and shifting of attention (e.g., so that useful feedback cues are detected).
- Interpret feedback / Support/Monitor student with interpreting feedback. (Subcategory of encourage/perform sensemaking.)
- Supplement inadequate mental model; seek or provide information about what student should be doing.
- Seek feedback / Support/Monitor student with seeking feedback about how they're doing (not about what they should be doing).

#### Give/receive outcome feedback

- using/from learning activity (e.g., simulation)
- from professor, lab assistant, or a teammate

#### Give/receive process feedback

- using/from learning activity (e.g., simulation).
- from professor, lab assistant, or a teammate.

### **Appendix I: Final Set of Codes**

1. Teach/Learn individual elements of mental model
2. Form rudimentary mental model
3. Develop fluency in use of mental model
4. Reveal/Recognize weaknesses in mental model (inaccuracies, flaws, misconceptions, simplifications, gaps)
5. Anticipate weaknesses in mental model
6. Metacognitive: self-reflection, self-evaluation;
7. Weave new learning into existing knowledge; connect new information to existing knowledge.
8. Student seeks and interprets feedback on his/her own; sorts out what happened on his/her own
9. Supplement inadequate mental model; seek or provide information about what student should be doing
10. Assist with/Improve the directing and shifting of attention (e.g., so that useful feedback cues are detected)
11. Interpret feedback/Support/Monitor student with interpreting feedback.
12. Seek feedback/Support/Monitor student with seeking feedback about how they're doing (not about what they should be doing)
13. Give/receive outcome feedback simulation, professor, lab assistant, team
14. Give/receive process feedback simulation, professor, lab assistant, team
15. Emphasis on performing or applying knowledge from the course
16. Either familiarity or unfamiliarity with material in the course
17. Benefit of hybrid methods
18. Building block strategy where material/information/knowledge in the course builds upon itself and is applied throughout the entire course
19. Expert ability to quickly diagnose how a student is performing
20. Background Information

## Appendix J: Final Codes with Example of Corresponding Data Element

Code	Data Element
1. Teach/Learn individual elements of mental model	Most of it, same-runway separation, you have got to know your aircrafts, you know, whether it is a Lear jet or a prop or a turbo jet or a super, like you have to know what aircraft is which because it really counts for same-runway separation.
2. Form rudimentary mental model	It allowed me to get a handle on the separation requirements before seeing it in the simulator. I kind of knew how to work the stuff and how to organize it rather than just reading the size aircraft and the times and things. We were able to think through it and be a little bit better prepared so when we saw it, it wasn't self-explanatory, but it was much easier to understand.
3. Develop fluency in use of mental model	Eventually it got to a point where it was a lot more natural and kind of second nature to separate the aircraft the way they were supposed to be.
4. Reveal/Recognize weaknesses in mental model	Sometimes it is a little bit harder to distinguish between the different weight classes and figuring out where on the runway they are and what kind of time they need and what aircraft is following them.
5. Anticipate weaknesses in mental model	On the first couple times they try this they might have one airplane landing on top of another because they didn't anticipate, they weren't sure at what point they could clear somebody for take-off or when they could clear somebody to land and so forth.
6. Metacognitive: self-reflection, self-evaluation	And you would practice it so much sometimes that you feel like something might be missing or it was too easy. So you go back and you might have to think about what you did and what you should have done.
7. Weave new learning into existing knowledge	So first thing we learned was same-runway separation. That was so the aircraft wouldn't get too close together and it would be illegal. Wake turbulence, we learned that, that is a further, it's like a refinement, you've added another level of sophistication to the rules. It's like refining a search on Google. This is the basic search within a webpage and this is a search for a keyword within a page.
8. Student seeks and interprets feedback on his/her own	That's how I sort of did it, I was like "Ok I am not going to give him the same heading, just give him a separate heading and then the next guy, here's another one, just give him the first heading." Small things like that. A lot of that was I figured out myself.
9. Supplement inadequate mental model; seek or provide information about what student should be doing	We also had the rules; I believe they were on the projector screen when we were practicing for the first couple times so that if we forgot the different types of separation we could just look up there and check as well.
10. Assist with/Improve the directing and shifting of attention	So we are actually looking out the simulated windows and pointing out where the 6,000 feet, 4,500 feet, and 3,000 feet for same-runway separation and they start to pick up their working speed because they realize that they are behind, they don't have it, they didn't understand it and suddenly the light comes on and they understand really what is going on.

11. Interpret feedback/Support/Monitor student with interpreting feedback	More typically, it is usually individuals, some people will pick up something very quickly and I will have to say very little to them. I will just watch and say, "Ok you got the hint" and as long as I am not saying anything to them, I think most of them understand and think, "Ok I must be doing this all right, so I'll just keep doing it."
12. Seek feedback/Support/Monitor student with seeking feedback about how they're doing	It was definitely in that retrospect but as a whole it was sort of, he gave us the PowerPoint, there was a whole bunch of questions, he helped us out, he explained it a little bit, and then it was sort of an on your own thing. "How are you doing? You still need some help? Ok here's the answer." It was one of those things.
13. Give/receive outcome feedback simulation, professor, lab assistant, team	You know he would say that we were doing a good job, but I mean nothing really like giving us a tip or a hint as to how to do it.
14. Give/receive process feedback simulation, professor, lab assistant, team	Having him in class and walking around and being able to, during the scenarios stop and ask him questions if what's going on is what we are supposed to be doing or in this situation how can we improve it, helped out a lot. Just a lot easier with the feedback and a lot easier knowing what we are supposed to be doing and when.
15. Emphasis on performing or applying knowledge from the course	Where you truly are going to find out whether you can be an air traffic controller and have the capability of being an air traffic controller is by performing.
16. Either familiarity or unfamiliarity with material in the course	Before it was introduced to me, I didn't really know what same runway separation was, I had heard the term, but I didn't know how to apply it, I didn't know the definition of it. I just didn't know anything about it really.
17. Benefit of hybrid methods	The biggest thing for hybrid is that it frees up the lab for students to have more time to get hands on practice running scenarios. If I didn't do a lot of this online, I would have to teach it or talk about it in class and that would only take valuable lab time where they could actually be practicing. So that, for me, is the number one thing.
18. Building Block Strategy	Each one builds on the previous on the previous one until in the end, in the final week or two, they have finally started putting it all together and realizing the building blocks have built up to the point where they are really moving the traffic quite well.
19. Expert ability to quickly recognize how a student is doing	For me, and I kind of think about this as I walk around the room, I've done it so much that I can just glance at somebody really quick. I mean in a matter of 2 seconds, how are they doing, ok they are doing good.
20. Background	The FAA pretty much expects or it is a given that you are going to be able to pass all the book work, take all the tests and stuff that they give you.

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### Appendix K: Detailed Code Descriptions

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<b>Code 1:</b>	Teach/learn elements of mental model
<b>Total Frequency:</b>	35 of 627
<b>Total Percentage:</b>	6%
<b>Theoretical Justifications:</b>	This code was used based on the postulate of CTT (Klein & Baxter, 2006) that mental models are central to developing expertise in cognitive work domains and was the primary reason why this code was used to describe this data set.
<b>Context:</b>	Operating under the above postulate in the code revision process, data elements were identified in which isolated knowledge pieces were discussed by either the professors or the students. This code was assigned for instances in which the professor or student described any activity or course component in which information was taught or learned and could be considered an individual piece of knowledge.
<b>Examples:</b>	<p>Professor:</p> <p>“What we do is we have them identify aircraft categories to start”</p> <p>Student:</p> <p>“Most of it, same-runway separation, you have got to know your aircrafts, you know, whether it is a Lear jet or a prop or a turbo jet or a super, like you have to know what aircraft is which because it really counts for same-runway separation.”</p>
<b>Note:</b>	<p>This code represents an initial stage of learning in that the accumulation of knowledge provided a foundation for the later integration, organization, and revision of knowledge that contributed to the formation of a mental model. A quote from one of the professor’s may describe the foundational aspect of this code:</p> <p>“So we lay that ground work for same-runway separation. So in teaching same-runway separation, it is all based on the type of aircraft that you are dealing with. In other words, they know the minimum. They know the type aircraft so that have that base already before they even start a scenario.”</p>

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<b>Code 2:</b>	Form rudimentary mental model
<b>Total Frequency:</b>	209 of 627
<b>Total Percentage:</b>	32.1%
<b>Theoretical Justifications:</b>	This code was used based on the postulate of CTT (Klein & Baxter, 2006) that mental models are central to developing expertise in cognitive work domains was the primary reason why this code was used to describe this data set.
<b>Context:</b>	Students were considered to form rudimentary mental models in instances where differing knowledge elements were either presented in an integrated way or students integrated them on their own, when learning opportunities allowed students to learn cause and effects relationships, and when students began to recognize the perceptual cues and patterns that matter in this domain.
<b>Examples:</b>	<p>Student:</p> <p>“I think just having seen it in the simulator, that if you see these planes you know what is going to happen and you have a picture in your head of what is going to happen or work. You started to notice patterns and I think that was a big part of what it was. I think that seeing the pattern kind of helped to learn really quick.”</p> <p>“When you actually have everything jumbled together and you are actually controlling the scenario, I just feel that that is a better learning experience. Whether you just jumped into it and are trying it out or if you already know the concept and you are trying it out that way, I think either way you are going to learn better.”</p>

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<b>Code 3:</b>	Develop fluency in use of mental model
<b>Total Frequency:</b>	50 of 627
<b>Total Percentage:</b>	7.8%
<b>Theoretical Justifications:</b>	This code was used based on the postulate of CTT (Klein & Baxter, 2006) that mental models are central to developing expertise in cognitive work domains was the primary reason why this code was used to describe this data set.

**Context:** This code emerged as a pattern in the data which suggested students were progressing beyond a rudimentary understanding of the material. In general, this code was applied in three types of contexts. The first context was where student's learned knowledge of ways to increase or improve performance or effectiveness. The second context this code was applied was when students' knowledge about routine cause-effect relations became automatized in that connections become stronger and better developed to support faster and more complete recall of relevant mental model elements. The final context that this code was applied was characterized by improved recognition of useful perceptual cues, patterns, and shifts where recognition becomes faster and difficult or subtle perceptual details become easier to distinguish.

**Examples:**

Professor:

“Once they get the basics down, once they get all the rudimentary, all the little finer points down; then we can take it to the next highest level; as far as moving airplanes the most efficiently. You can be safe, ok, you can still have plenty of separation between airplanes, ok you are safe, but here again, if you have got 15 airplanes waiting to take off because you are allowing so much room, you are going to be making a lot of people unhappy that they missed their flights or connections because of this. So now we have got to be also very expeditious so we have to maximize everything so that everything we do is to the maximum benefit, not only for safety but for efficiency.”

Student:

“Eventually it got to a point where it was a lot more natural and kind of second nature to separate the aircraft the way they were supposed to be.”

“Applying rules is a little bit trickier because it's not just straight memorization and regurgitation. You have learned it and now it's an intuitive part of you.”

“You get used to seeing planes at an intersection that are going to wait three minutes if they are this size. You just kind of come to recognize, ‘ok he is this size and he is at this intersection, 3 minutes.’ So you can just kind of look at it.”

“You basically learn your types of aircraft and when you see that aircraft you automatically think, ‘that's a heavy.’”

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**Code 4:** Reveal/Recognize weaknesses in mental model

**Total Frequency:** 63 of 627

**Total Percentage:** 9.8%

**Theoretical Justifications:** This code was implemented in accordance with the CTT postulate that in order for individuals to revise or develop more accurate mental models, realization of a weakness in his or her mental model must occur.

**Context:** This code was used in contexts where a student either recognized a weakness on their own or a professor or lab assistant recognized a weakness and revealed it to the student.

**Examples:** Student:

“We would at times go through and review the different subject areas and I think that just through class participation he could tell who had a good handle on things and who may have been kind of weak in areas.”

“The whole point of working together is that you can catch other peoples’ mistakes.”

“I think definitely the teachers and the simulators. I think even if you just had the simulators you still wouldn’t be as good because you could still get stuff going but you’d probably be making the same mistakes over and over.”

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**Code 5:** Anticipate weaknesses in mental model

**Total Frequency:** 16 of 627

**Total Percentage:** 2.9%

**Theoretical Justifications:** This code was used based on the postulate of CTT (Klein & Baxter, 2006) that mental models are central to developing expertise in cognitive work domains was the primary reason why this code was used to describe this data set and that in order for individuals to revise or develop more accurate mental models, realization of a weakness in his or her mental model must occur.

**Context:** This code was emergent in the data and was mostly used by the professor in anticipation of students encounter a learning difficulty such that it could be a precursor to revealing or recognizing a weakness.

**Examples:** Professor:

“I expect separation errors frequently when we first start this because they are just learning ‘Ok, I need this distance and this airplane is a lot faster than I thought it was would be’ and stuff like that.”

“There is always those students that don’t quite get what you are telling them, though you tell them three different ways and so I give them a fourth way.”

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**Code 6:** Metacognitive: self-reflection, self-evaluation

**Total Frequency:** 20 of 627

**Total Percentage:** 3.3%

**Theoretical Justifications:** The reason this code was used was based on predictions that metacognitive activities would be evident in learning for complex cognitive work domains and that it was observed during the course observations.

**Context:** This code was primarily used in contexts where students self-reflect or self-evaluated and was based on emergent patterns in the data.

**Examples:** Professor:

“They take the quizzes and it is a way for them to self-evaluate themselves as to do they know the information or not.”

Student:

“It was just kind of you look around you and you can see where all your peers are at, so I think it was a lot of self-motivation too. You know you need to be on this or you will fall behind.”

“Yea when I first started it was like more sporadic. It was, ‘Oh crap. I need to do this or I didn’t do that. I did do this, but not before I did this.’”

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**Code 7:** Weave new learning into existing knowledge

**Total Frequency:** 8 of 627

**Total Percentage:** 1.3%

**Theoretical Justifications:** This was used based on the postulate of CTT that learning in cognitive domains is not only about adding information rather it is about integrating information with existing knowledge.

**Context:** The primary context this code was used was in the case that students would relate knowledge they had prior to taking this course with information presented in this course or when material previously covered within this course was related to the material currently being learned.

**Examples:** Student:  
 “Yea [radar] seemed very similar. It was presented in a way similar to the way my TRACON classes had presented it before. So I was very familiar with using a radar, so like I’m familiar with it now I just have to learn to use it for this scenario.”  
 “In [ATC] Basics, you’d learn it but you would never really use it ... I didn’t really know what it was, and in this class I was like ‘Oh this makes sense now.’”

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**Code 8:** Student seeks and interprets feedback on his/her own

**Total Frequency:** 5 of 627

**Total Percentage:** 0.7%

**Theoretical Justifications:** This code was used in order to capture any instances in which students were able to figure things out on their own in accordance with the postulate of CTT that ultimately developing expertise for cognitive work should lead to this point.

**Context:** This code was used in contexts where either the professor describes the students’ process of figuring out the separation on their own or instances where to students explicitly state how they figured out how to use the separation on their own.

**Examples:** Professor:  
 “Then they watch it happen. Maybe they cleared him too soon so you don’t have that separation between them, so next time wait just a little bit longer. So it is kind of like a trial and error practicing this.”

Student:  
 “That’s how I sort of did it, I was like ‘Ok I am not going to give him the same heading, just give him a separate heading and then the next guy, here’s another one, just give him the first heading.’ Small things like that. A lot of that was I figured out myself.”

**Code 9:** Supplement inadequate mental model; seek or provide information about what student should be doing

**Total Frequency:** 41 of 627

**Total Percentage:** 6.5%

**Theoretical Justifications:** This code was used based on the postulate of CTT (Klein & Baxter, 2006) that mental models are central to developing expertise in cognitive work domains was the primary reason why this code was used to describe this data set. More specifically, Klein and Baxter describe the just-in-time use of mental models to account for novel situations and this was characterized by code.

**Context:** The code was primarily used in contexts where either the professor provided just-in-time information regarding what the student should be doing so that the student would not experience a lapse in performance or the student would seek supplementation for a weakness in their mental model either from the professor, team mates, lab assistants, or some type of memory aid, so as to avoid a lapse in his or her performance.

**Examples:** Student:  
 “So to have the teacher not only do you have the picture right there but also the rule books, so to say, and having the teacher kind of over you making sure you are doing it right.”

“Having him in class and walking around and being able to, during the scenarios stop and ask him questions if what’s going on is what we are supposed to be doing or in this situation how can we improve it, helped out a lot.”

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<b>Code 10:</b>	Assist with/Improve the directing and shifting of attention
<b>Total Frequency:</b>	20 of 627
<b>Total Percentage:</b>	3.5%
<b>Theoretical Justifications:</b>	The was derived from the CTT postulate that in learning in cognitive work domain is dependent on teaching individuals the information that matters, when to seek that information, and when information is irrelevant.
<b>Context:</b>	This code was primary used in contexts where the professor or lab assistant would provide information to the students that helped them improve the direction of his or her attention so they could learn what information matters and when the information matters.
<b>Examples:</b>	<p>Professor:</p> <p>“They start seeing their labs assistants and their professors pointing out to them, that aircraft should be lining up to be out there on the runway, you should be clearing him for take-off already, you can clear him to land because you have this separation.”</p> <p>Student:</p> <p>“At least he told me, when I was working clearance, to make sure that I was paying attention to what was going on in ground and tower.”</p> <p>“It helped out having an idea going into class of what we were going to be doing and looking over it and knowing how to use the different rules and then when we get into class we are not just wasting time with the scenario.”</p> <p>“So it’s more just learning how to keep other people tuned in while keeping whoever you don’t need, like the other two groups, tuned out, which is a good skill to have.”</p>

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<b>Code 11:</b>	Interpret feedback/Support/Monitor student with interpreting feedback
<b>Total Frequency:</b>	14 of 627
<b>Total Percentage:</b>	2.3%



<b>Theoretical Justifications:</b>	This code specifically relates to feedback which was one of the learning components described by CTT and this code specifically was emergent through patterns in the data elements.
<b>Context:</b>	This code was primarily used in contexts where students were supported by their professor or lab assistant in the interpretation of feedback from the simulator as students were controlling the aircraft. In these instances students were not specifically told what or how to do something but were questioned on the current situation or asked to explain the actions they just took in a prior scenario.
<b>Examples:</b>	<p>Student:</p> <p>“A lot of times he would ask questions about why I did a certain separation and most of the time when I would explain it I would realize it was an incorrect form of separation.”</p> <p>“Even if you are right and they say, “Why did you do this?” You explain yourself and they say ‘Ok.’ It’s just really to see that you know what you are doing.”</p>

**Code 12:** Seek feedback/Support/Monitor student with seeking feedback about how they’re doing

**Total Frequency:** 5 of 627

**Total Percentage:** 0.7%

<b>Theoretical Justifications:</b>	This code specifically relates to feedback which was one of the learning components described by CTT and this code specifically was emergent through patterns in the data elements.
<b>Context:</b>	This code is differentiated from the previous code through the context in which it was applied. This code was primarily applied in contexts where the professor or lab assistants specifically supported or monitored students with figuring out how they were doing in terms of following the rules for separating the aircraft.
<b>Example:</b>	<p>Student:</p> <p>“It wasn’t a progressive help it was like here it is, see how you do, ok you aren’t doing so well, I’ll help you some more.”</p>

**Code 13:** Give/receive outcome feedback simulation, professor, lab assistant, team

**Total Frequency:** 1 of 627

**Total Percentage:** 0.1%

**Theoretical Justifications:** This code was used in attempt to make a comparison between the types of feedback provided in the class, however, the students or professors did not really describe types of feedback that would be considered outcome feedback.

**Context:** The only instance it was used, illustrated in the quote below, was when a student describes the feedback she received from the professor regarding her performance.

**Example:** Student:  
 “You know he would say that we were doing a good job, but I mean nothing really like giving us a tip or a hint as to how to do it.”

**Code 14:** Give/receive process feedback simulation, professor, lab assistant, team

**Total Frequency:** 42 of 627

**Total Percentage:** 6.8%

**Theoretical Justifications:** This code specifically relates to feedback which was one of the learning components described by CTT and this code specifically was emergent through patterns in the data elements. More specifically, this code represents the process feedback that was recommended by Klein and Baxter (2006).

**Context:** This code was primarily used in contexts where students were given feedback that indicated to students the way in which they could improve their performance. The other context in which this code was applied was when students would give feedback that helped their teammates improve their performance

**Examples:**

Professor:

“You don’t have the separation. Ok, we need to lengthen that, here practice. Ok now you have got way too much so you are going to need to get just the amount of time that you are going to need without going too much over it.”

“The advantage of groups is often times, those that are struggling a little bit, are helped by those next to them working in their group. So you do have the strength of some helping those that pick it up less quickly than others.”

Student:

“Either a lab assistant or the professor is right there and they are helping you and saying ‘You need to be doing this, this is where you need to apply this rule, you are doing this wrong.’”

“Typically, the good ones will just let you run the scenario and then tell you ‘Hey you need to improve this’ and will give you an opportunity to just do it.”

“We were encouraged to scan and help, especially if we didn’t have much going on, to help assist the other positions. That did help; we have done that a few times throughout the semester, just kind of pointing things out that maybe somebody missed or if they had a question about something, being able to ask each other.”

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<b>Code 15:</b>	Emphasis on performing or applying knowledge from the course
<b>Total Frequency:</b>	31 of 627
<b>Total Percentage:</b>	5.1%
<b>Theoretical Justifications:</b>	This code was purely used because it was an emergent trend in the data.
<b>Context:</b>	The code was used in any context where the student or professor emphasized the importance of actually using the knowledge covered in the course through performance or application.

**Examples:**

Professor:

“Their last performance appraisal is really worth a significant amount of their grade. So the class is weighted heavily towards performing not towards filling in the right answers on a test; so it is actually doing and the students know that.”

“It is the application though, I am convinced, the way we have it set up. The application is really where it drives it home as to what the concept is that we are trying to teach them.”

Student:

“So while you spend a lot of time learning and memorizing things, just like you did in the other courses, learning rules and such, but you also get to apply them. By applications I mean you spend time in a lab actually controlling.”

“You can take tests and take quizzes but that’s not what you are going to be doing in real life. You are going to need to be doing what we are doing in the lab in real life and just see that you can do it right is probably the best way that they did that.”

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<b>Code 16:</b>	Either familiarity or unfamiliarity with material in the course
<b>Total Frequency:</b>	11 of 627
<b>Total Percentage:</b>	1.8%
<b>Theoretical Justifications:</b>	This code was used based on it being an emergent trend in the data.
<b>Context:</b>	This code was used in context where students described their knowledge or lack of knowledge of the material being taught in the course.
<b>Examples:</b>	<p>Student:</p> <p>“Well when it [same-runway separation] was first introduced I was new to it. So I didn’t have any clue that it even existed.”</p> <p>“Before it was introduced to me, I didn’t really know what same runway separation was, I had heard the term, but I didn’t know how to apply it, I didn’t know the definition of it. I just didn’t know anything about it really.”</p>

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<b>Code 17:</b>	Benefit of hybrid methods
<b>Total Frequency:</b>	12 of 627
<b>Total Percentage:</b>	1.8%
<b>Theoretical Justifications:</b>	This code was used based on it being an emergent trend in the data.
<b>Context:</b>	This code was applied to contexts where the professors or students referred to some aspect of the hybrid course that was considered to be beneficial.
<b>Examples:</b>	<p>Professor:</p> <p>“The biggest thing for hybrid is that it frees up the lab for students to have more time to get hands on practice running scenarios. If I didn’t do a lot of this online, I would have to teach it or talk about it in class and that would only take valuable lab time where they could actually be practicing.”</p> <p>“The way we set it up, with the hybrid portion, they can go back and look at that lecture 5 times is they want.”</p> <p>Student:</p> <p>“The nice thing about this hybrid course is having it there. So you can feel like you can go back and look at it whenever and you feel like you are just a little bit more prepared than just coming into class learning it immediately and then doing it immediately.”</p>

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<b>Code 18:</b>	Building Block Strategy
<b>Total Frequency:</b>	9 of 627
<b>Total Percentage:</b>	1.4%
<b>Theoretical Justifications:</b>	This code was used based on the prevalence of the strategy initially noticed during examination of the course artifacts and course observations as well as an emergent trend in the data.

**Context:** The context that code was used was when professors or students would mention the blocks in the course or the way in which the information presented in each block would build upon the information presented in the previous block.

**Examples:** Professor:  
 “Each one builds on the previous on the previous one until in the end, in the final week or two, they have finally started putting it all together and realizing the building blocks have built up to the point where they are really moving the traffic quite well.”

Student:

“Once you have learned a rule, at least in this course, and maybe all air traffic courses, once you learn a rule, that rule is always going to be in effect. You know it, and you are expected to know it, and you are expected to use it properly.”

**Code 19:** Expert ability to quickly recognize how a student is doing

**Total Frequency:** 3 of 627

**Total Percentage:** 0.4%

**Theoretical Justifications:** This code was used based on its emergence in one of the professor’s transcription and that it was a characteristic of expertise described in CTT.

**Context:** This code was used for instances in which the professors indicated that they had an ability to quickly recognize and evaluate a students’ performance when compared to someone with less experience.

**Example:** Professor:  
 “I kind of think about this as I walk around the room, I’ve done it so much that I can just glance at somebody really quick, I mean in a matter of two seconds ‘how are they doing? Ok, they are doing good.’”

**Code 20:** Background

**Total Frequency:** 32 of 627

**Total Percentage:** 5.3%

**Theoretical  
Justifications:**

N/A

**Context:**

This code was primarily used in a context where the professor or student provided information to the researcher that helped to better describe a topic or in instances where the information was considered off topic and not pertinent to this research.

**Examples:**

Professor:

The FAA pretty much expects or it is a given that you are going to be able to pass all the book work, take all the tests and stuff that they give you.

Student:

From a ground a clearance point of view, it didn't really seem like much, but I guess just rotating it and doing it a lot is what helped. But from ground and clearance, I didn't feel like that helped any, because I have done ground and clearance a lot, the way we rotate in class I didn't really get much time on local, so that's why I was frustrated too because every time I have gotten to it I have never had much time on it.

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