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Naturalistic Study Examining the Data/Frame Model of Sensemaking by Assessing Experts in Complex, Time-Pressured Aviation Domains

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by:

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Abstract

Research on expert chess players, radiologists and landmine detection personnel suggests a use of cognitive frameworks, alternatively referred to as schemas, templates, scripts, frames and models, to effectively perceive, interpret, understand, recall, and anticipate information. These experts may use cognitive frameworks to capture past experience in ways that support rapid pattern recognition, adaptive responses and proactivity. The proposed research approach assumes that experienced pilots will similarly rely on cognitive frameworks to handle information and make sense of complex, fast-moving situations experienced in their information-dense environments. Predictions from Klein et al.'s (2006) Data/Frame Model of Sensemaking were used to evaluate event-based interview data collected from uninhabited aerial system (UAS) pilots and high performance military aircraft pilots (F-16 and UH-60 Black Hawk) in order to assess the methods with which these experts handle large amounts of critical information in their operations. This effort may benefit the sensemaking model, a model based largely on domains in which situations unfold over time and decision-making can be adapted, such as in information operations, nursing and fire fighting, by comparing its predictions with data collected from UAS pilots. The UAS operations domain, in particular, has characteristics that differ from those of domains on which the model is based because UAS pilot sensemaking must support decisions and continuous adjustments of an aircraft operating in a dynamic, potentially complex, and rapidly shifting environment from which the pilot is physically removed. The military aviation domain may be similar to studied domains that some decisions need to be made rapidly, and situations can change rapidly; nevertheless, as a new domain to the model, offers the potential to reveal new insights. Based on this research, recommendations are offered for

aviation training and other information-rich domains, and evidence is provided that addresses the question, “How much information can a person handle?”

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List of Abbreviations

CDM	Critical Decision Method
COA	Certificate of Authorization
COCOM	Contextual Control Model
FAA	Federal Aviation Administration
GCS	Ground Control Station
IP	Instructor Pilot
NAS	National Air Space
PIC	Pilot in Command
RPD	Recognition Primed Decision
SAC	Strategic Air Command
SME	Subject Matter Expert
STM	Short Term Memory
UAS/UAV	Uninhabited Aerial System/Uninhabited Aerial Vehicle
WM	Working Memory

Introduction

"…You just – you pull all of this data together, this amazing amount of data to deal with the situation" (anonymous pilot, personal communication, 2010). Many professional domains require people to manage large amounts of incoming data in order to successfully complete their tasks. Some tasks may be harder than others, but with experience, we are somehow able to manage this large amount of information in order to comprehend our current situation. The purpose of this research is to study and understand the strategies and techniques successfully used to manage and make sense of large amounts of information under time pressure. Knowing how experienced professionals make sense of large amounts of information under time constraints can offer insight into how individuals can be more effectively trained. This research additionally contributes to a greater understanding of the limitations on - or extent of - just how much information people can handle in fast-paced, information-dense work environments.

The experienced professionals studied in this effort were professional pilots of a military helicopter, military high performance jet and mid-sized uninhabited aerial systems (UASs). These pilots frequently operate within a complex, rapidly shifting, time-pressured, information rich landscape. In addition, the UAS pilots must cope with challenges associated with controlling their aircraft from afar. Due to not being physically immersed in the aircraft's environment, crews must piece together incomplete information to understand their fast-moving, dynamic and complex situation. Although the information they receive is probably never quite sufficient, the UAS is still using large amounts of this data in order to detect and assess changes that, in traditional flight, are often hard to miss because the pilot is physically immersed in the aircraft environment. All three types of pilots additionally deal with interruptions, complex interfaces and rapidly changing environments. Another contributor on cognitive load is technology. As information technology advances, more and more of it and thus more and more information is being placed within the cockpits of both manned and unmanned aircraft to aid the pilot.

The current study builds on an extensive body of work, dating back decades, that explores the nature of expertise. A portion of this body of work will be reviewed in the pages that follow; the review highlights the role of knowledge structures in expertise and sets the stage for the presentation of a theory of sensemaking in which the knowledge structure is a central construct. The theory's presentation, in turn, sets the stage for introducing this study's research methods, which are significantly influenced by the Data/Frame model. A second theory also influenced the data analysis. This theory, called the Contextual Control Model (COCOM), by Hollnagel (2002) will also be discussed in this study's introduction.

The Nature of Expertise

Expert attributes that contribute to operating with large quantities of information in rich, dynamic environments are discussed by Chi (2006) in her synthesis of three decades of expertise research. Chi presents a list of positive and negative characteristics of experts, which are presented below.

Experts' positive characteristics include the ability to excel in their area of expertise by detecting features that may be difficult for novices to see, experts spend more time than novices assessing the problem space before beginning to take action and generating an effective solution to problems more quickly and accurately than novices. They are also able to detect errors because of increased self-monitoring; implement adaptive strategies, such as working backwards with difficult physics problems; and are opportunistic in strategically drawing upon all available information to generate an answer or solve a problem. Experts are said to recognize and assess the knowledge they need with minimal cognitive effort versus novices who expend effort searching for what information to attend to, something that could pose a major problem in aviation because many scenarios are time sensitive.

Although it may seem counterintuitive to say that there are negative characteristics of expertise, Chi believes the domain specificity of expertise can be considered negative, that is, experts only excel in the area in which they have extensive experience. Chi also sees the tendency to be overconfident as a problem because it can lead to biased and premature judgments and cause experts to overlook details. Finally, according to Chi's review, experts tend to underrate the performance of novices and may be slower than novices to adapt to new rule sets, which Chi terms as "inflexible" (p. 26).

Dreyfus and Dreyfus (1980) focus on perception in expertise, describing how the perception of an environment changes as an individual progresses from novice to expert. This progression happens naturally as the skills taught are relied on less than the actual experiences gained, resulting in an individual who can operate fluently in their respective domain. Dreyfus and Dreyfus gathered and analyzed personal accounts of individuals studying foreign language, chess and flight instruction to understand the changes that occur in perceiving one's environment when learning skills and attempting to reach expertise. They concluded that in order to reach expertise learners must travel through five interlocking stages: novice, competence, proficiency, expertise and mastery.

According to Dreyfus and Dreyfus, during the novice stage, the individual sees context-independent features in the surrounding environment and breaks down the environment into different features that do not yet have a meaning as a whole. By monitoring the dynamics of the environment overtime, the individual will construct rules about features to guide his or her behavior. In the next stage, competence, the individual has gained experience and begins to perceive these features as a part of a larger context. The features are now seen in meaningful context and patterns, referred to as aspects, and can be recognized. Dreyfus and Dreyfus suggest instructors can establish action guidelines to aid students in assigning meaning to features and discovering patterns. To form these guidelines, individuals will observe and gather as many aspects of the scenario as possible by not showing favoritism or wrongly treating some as more influential than others. The third stage, proficiency, is marked by goals. The individual now perceives the features of his or her task in terms of how they contribute to a final goal.   Here, individuals use maxims or memorized rules to determine the needed behavior for the specific scenario. Finally, expertise is reached once the individual has the ability to recognize the appropriate action to a given situation immediately and without any aid. Dreyfus and Dreyfus go further to say that mastery can be reached but only when the expert no longer pays close attention to his or her behavior and can fluently produce appropriate behavior because the individual relies on his past learning experiences.

These stages of expertise development are important to understand during the formation of training programs. They are also suggestive of the increasing capacity for handling complexity and information loads as expertise develops. As will be seen, Klein, Moon and Hoffman (2006) describe the goal of sensemaking in a way that is similar to Dreyfus and Dreyfus's (1980) description of mastery, where the individual perceives his or her environment as a whole learned experience and not just in individual characteristics with no connection.

Work by Ericsson and his colleagues also add to the understanding of expertise and how it develops. In a comprehensive review, Ericsson and Lehman (1996) convey characteristics of experts that allow them to accomplish their goals effectively, most of the time. In order to find shared characteristics across experts, Ericsson and Lehman propose studying the behavior of experts, specifically, how they adapt to their environments across multiple domains. They also believe that it is important to test experts' ability to consistently reproduce advanced, skilled performance in order to understand the limits of expertise and that this research can be done by studying expert performance in controlled laboratory settings.

The number of years of experience needed to reach peak performance varies by domain; for example, peak performance is reached in the earlier years in sport and athletic domains due to the physical stress placed on the body. Many researchers hold that a minimum of ten years is needed to reach expertise in a domain (Ericsson & Lehman, 1996). Ericsson, Krampe and Tesch-Römer (1993) additionally advocate deliberate, concentrated practice during that time period. Their studies have shown that four hours a day of deliberate, concentrated practice can be executed before exhaustion has been reached. Ericsson and Lehman's (1996) main assertion is the importance of deliberate practice over innate ability in attaining expertise.

Studies of exceptional memory have provided additional insight into the abilities and characteristics of experts. The use of digit sequence recall is a popular laboratory experimental task used to study exceptional memory. In one study, subject SF, an undergraduate, was quickly read digit sequences and then asked to recall as many digits as possible (Ericsson & Chase, 1982). If SF was correct, the experimenter added a single digit. If SF was incorrect, the experimenter subtracted one digit. This was repeated for a significant amount of time, roughly 230 hours in the laboratory spanning 20 months. They discovered that SF, an average student, was able to recall more digits as the testing continued. SF was able to recall roughly eighty digits, whereas most people can recall seven to ten. Expert mnemonists have not reached eighty digits, leading Ericsson and Chase to speculate how and why SF was able to recall these long digit spans. They discovered that SF was attaching meaning to certain number sequences, such as familiar running times he received in the past as a competitive track racer. This investigation led to Skilled Memory Theory (Ericsson & Chase, 1982). Skilled Memory Theory proposes that an individual can become an expert in memory recall by using short-term memory aids that build long-term memory. According to Skilled Memory Theory, associating new information to already known material can aid in memorization. The use of this strategy to boost memory for domain-specific information has been documented in studies of waitresses and waiters remembering drink and food orders (Bennet, 1983; Ericsson & Polson, 1988). Skilled Memory Theory asserts that this technique extends the otherwise limited capacity of the working memory. Alan Baddeley (1992) defined working memory as, "a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning and reasoning" (p. 556). Consistent with Ericsson and Lehman's (1996) theory of deliberate practice and Ericsson and Chase's (1982) skilled memory theory, Maguire, Valentine, Wilding and Kapur (2003) found that IQ scores and ability to recall faces and snowflakes do not relate to recall performance in memory champions. These researchers demonstrated the importance of the cognitive strategy used. They found that memory champions all used a memorization strategy called the method of loci, or mental walk, during the study phase of the memory tests whereby experts visually connect items to-be-remembered to specific locations in a familiar setting as they walk through the setting. Use of the method of loci is yet another case of experts using experience-based knowledge structures to benefit performance. Because stimuli were novel and devoid of meaning, they did not match a mental pattern; consequently the expert mnemonists had learned to generate a framework – the familiar setting – and fit the information into it.

As part of the process of developing exceptional memory, students studied by Ericsson and Chase (1982) seemed to develop organizational structures in long-term memory. Retrieval cues were mapped to the organizational structure; Ericsson and Chase refer to these as "retrieval structures." The strategic use of organizational structures is a frequent finding in studies on expert – novice differences (e.g. Chi, 2006; Lesgold et al., 1988) and is central to the goals of the present research.

The Role of Organizing Knowledge Structures in Expertise

This review will use many different terms to describe knowledge structures and mental models. In particular some researchers refer to knowledge structures as frames (e.g., Klein et al., 2006), while others refer to them as schemas and scripts (e.g., Bartlett, 1932, as cited in Roediger, Bergman, and Meade, 2000) and others use the term templates (Gobet and Clarkson, 2004). Despite their use of different terms, the researchers are referring to the fundamentally same construct. The review will maintain the term used by each researcher describing their work. Otherwise, the term 'knowledge structure' will be used.

Numerous studies demonstrate the expert's ability to use knowledge structures and techniques to handle complex and possibly large amounts of information. Since the 1960s, the game of chess has been heavily studied to examine the characteristics of expertise. Other domains studied to shed light on the role of knowledge structures include radiology and landmine detection. According to this research, experts use knowledge structures to organize knowledge and incorporate new information. They also help experts organize perceptual information into patterns that reflect regularities within the environment. Examples of this use of knowledge structures are described below.

The Use of Mental Representations from Experience. One of the ways experts seem to handle large amounts of information is by chunking, a construct introduced into researchers' vocabulary by Miller (1956) and studied by many over the decades since. Miller (1956) defined the term chunk as a "familiar unit" into which we organize or group information. We may only hold a limited number of chunks within our working memory; however, we can increase working memory capacity by grouping more information together into larger and larger chunks.

In order to research the size of chunks and how much information we are able to hold in these familiar units, expert chess players have been widely studied by researchers. Chase and Simon (1973) investigated Miller's Discrete Chunking Theory (1956) by studying master chess players' ability to recognize patterns of the chess pieces in their working memory (WM) in order to choose the "next best move". Chase and Simon (1973) set out to discover chunk size in experts, the difference in number and size of chunks of master versus weaker players, and how many chunks could plausibly be held in their WM.

In Chase and Simon's work, three chess players, a master, a Class A player and a beginner, performed a perception task and a memory task using twenty game board configurations including one random board configuration. The configurations ranged from middle-game positions to end-game positions and included a configuration of randomly selected positions. The perception task featured two boards, side by side, separated by a partition blocking the view of the left board. The right was a blank board for the participant to use to recreate the configurations modeled on the left board. Upon removal of the partition, the participant was instructed to recreate the left game board configuration on the right board and was free to look at the left board as needed. The memory task was similar to the perception task; however, the partition was replaced after five seconds of viewing the left board and the participant would attempt to recreate the configuration from memory using the right board. The participant was not time restricted when recreating the board. The task was repeated with each game board configuration until the player reconstructed the model with a 100% accuracy.

The memory task revealed that board reconstruction performance was related to rank of the individual; the master was able to remember more pieces correctly in a shorter amount of time and it took fewer trials to reach 100% accuracy when compared to the beginner and middle ranked player. However, the recall of random positions produced no correlation between memory task performance and player skill level. Class A and master players had worse recall of random positions than the beginners. Chase and Simon hypothesized that random positions did not facilitate the experts' use of chunks or recognition of patterns.

Chase and Simon used the perception task to assess the size of the chess players' chunks. To assess sizes of chunks using the perception task, Chase and Simon first looked at the amount of time between placements of pieces. They hypothesized that long pauses would separate two different chunks and short pauses would mean the pieces belonged to the same chunk. Chase and Simon discovered that masters are able to hold larger chunks of about five pieces, and that the number of chunks would be limited, just as for any other person, to a capacity of about seven plus or minus two items.

Using probability analysis to assess glances, they determined players grouped pieces primarily on the basis of location, color and attack or defense relations among pieces. Pieces related in these ways tended to follow one another in recall chains and tended to be separated by shorter pauses. Surprisingly, this held true for randomly positioned pieces also. They also discovered that with fewer similarities between pieces, the chess players needed longer glances in order to remember the positions in a given configuration. Again using probability analysis, they found that longer pauses, those over two seconds, indicated that different chunks were being used and that the similarities among the pieces in a given chunk were fewer.

Gobet and Clarkson (2004) replicated Chase and Simon's 1973 experiment; however, they used a computer-based chess game to account for the "hand size problem" that they hypothesized had affected Chase and Simon's results. Specifically, they wanted to test whether chess players in Chase and Simons' study were limited in the number of pieces they could fit in a hand at one time. Maybe pauses related more to hand size limits than to chunk limitations. In addition, Gobet and Clarkson sought to use their results to compare predictions of Discrete Chunking Theory with Gobet and Simon's (1996) Template Theory.

Discrete Chunking Theory (Miller, 1956) and Template Theory*,* proposed by Gobet and Simon (1996), make different predictions about the number and size of chunks held in working memory. Template theory suggests masters should be able to hold even larger chunks of fifteen pieces rather than those just the five proposed by Chase and Simon. More specifically, Template Theory predicts that chunks are combined into a more encompassing type of knowledge structure called a Template. Templates are described as organizing frameworks that tie together related chunks.

Using the computerized version of Chase and Simon's perception and memory tasks, Gobet and Clarkson discovered their participants tended to recreate larger, but fewer, chunks in comparison to Chase and Simon's findings. Using two different presentation techniques, a computer and real-life chessboards, the experimenters assessed their hypotheses about the hand-size confound in the Chase and Simon experiments. They hypothesized that if chunking theory explains expert chess memory, chunks should not exceed four to five pieces for both real-life chessboard and computer presentation conditions. On the other hand, if template theory explains expert chess memory, the real-life chessboard presentation condition would produce smaller chunks due to hand limitations and the computerized presentation condition would produce larger chunks (sometimes more than 15 pieces in size).

Gobet and Clarkson's participants were given two different tasks, a copy task and a recall task for both the real-life chessboard presentation condition and the computerized presentation condition. During the copy task, they were allowed to switch back and forth between the model board and their reconstruction board as much as they wanted. The recall task restricted the participants to viewing the model board for only five seconds before reconstructing what they could. They hypothesized that more glances to the model board meant smaller chunks were being used, whereas if the participant had longer glances, fewer, larger chunks were being used.

Gobet and Clarkson's results suggested that template theory gives a more accurate account of the organizational structure and capacity of working memory. Specifically, they found that in the real-life chessboard presentation condition, participants looked at the board for a short period of time before placing a few pieces on the reconstruction board. In the computerized presentation condition, the participants examined the board longer before placing a greater number of pieces on the reconstruction board. Gobet and Clarkson believed this was due to the use of fewer, larger chunks.

Gobet and Clarkson found that experts are able to hold larger chunks in working memory when recreating positions if they are not limited by hand-size. Thus this research provides evidence that the original chunking theory underestimated the size of chunks used by masters, and supported the template theory. As Chase and Simon before them, Gobet and Clarkson demonstrated that regardless of any basic limitation on the number of items that can be held in our working memory, experts can overcome those limits by the use of large chunks, i.e. templates.

According to Gobet and Clarkson, it is possible that experts use chunks as proposed by Simon and Chase; however, the chunks are larger than Simon and Chase estimated, allowing for more information to be comprehended. In addition to the suggested expertise research is the use of search-ahead techniques where the player "plans by looking ahead at possible moves, possible responses by the opponent, possible responses to those responses, and so on" (Gobet & Simon, p. 3). To examine whether expert chess players recognize patterns and features to guide their choice of moves or if they engage in look-ahead search to determine possible moves, world champion Gary Kasparov was studied by Gobet and Simon (1996). Kasparov was allowed to prepare for the games in the experiment by studying past games of his opponents to learn where his opponents regularly made mistakes. While normal chess play is held to three minutes for each move, Gobet and Simon (1996) limited Kasparov to three minutes for each round of chess. This short amount of time was used to force Kasparov to depend on recognition of his opponents' mistakes, and not allow the use of a "search ahead" technique. He played against six opponents who were allowed the normal three minutes to respond to a move by Kasparov. Armed with the knowledge of their play characteristics, Kasparov tried to push his opponents into compromising positions he learned by studying their mistakes from past games. They found that even due to the limited time Kasparov was allotted, he was still able to play at the grandmaster level presumably by using recognition cues of mistakes.

Chabris and Hearst (2003) challenged Gobet and Simon's assertion that expert chess players engage in recognition processes by examining the results of twenty-three grandmasters. They assessed chess playing during six tournament events between 1993 and 1998 in which game playing was blindfolded (no sight of pieces' actual positions; only an empty board on a computer screen was provided) or rapid (normal rules however time restrictions added). These events were compared to classical play results by the same pairs of players during other events.

Using ChessBase, a database of game play and results, Chabris and Hearst determined that grandmasters made fewer errors during classical games where they are allowed more time and actual sight of the board. The results supported their hypothesis that when allowed more time, chess players engage in forward search to enhance performance. However, there was no significant difference in amount or magnitude of errors during blindfolded play versus rapid play. They suggest that both pattern recognition and searching ahead are influential to chess skill. While they cannot firmly suggest chunking theories are influential, they do support the notion that organizational knowledge structures, which support pattern recognition and search-ahead, are fundamental to effective expert performance.

The main findings from the review of chess literature support the present research on use of an organizational knowledge structure to enhance expert ability within a domain. They also shed light on techniques the knowledge structures make possible, whether these are searching ahead for patterns or the immediate recognition of patterns from memory. Expert aviators in the present study may also use an organizational knowledge structure built from experience to handle the incoming information and support immediate recognition of patterns.

Schema Use. Research on expertise in the field of radiology is relevant to the current research on expertise in aviation due to the perceptual demands the experts in both domains are required to deal with. Lesgold et al. (1988) examined radiologists and radiology residents in their naturalistic work setting. The participants were novice (first and second year radiology residents) and experts (radiologists with ten or more years following residency). The first experiment was similar to their daily operations where they examined x-rays and orally reported their diagnosis. After not finding differences among diagnoses that aligned with level of experience, they conducted a second experiment in the same setting but required them to circle areas of the x-rays influential to their diagnoses.

In the initial study, expert doctors, first-year and second-year radiology residents were instructed to not only assess and report orally diagnoses of x-rays, but to also draw circles around the patterns in each x-ray on which they were basing their diagnosis. Out of fifteen films, the experimenters focused on three films that were known to be difficult to analyze. The researchers assessed and compared the x-ray markings and verbal protocol of the diagnostic process. The researchers determined that all participants generated a mental representation or schema of the case to guide the diagnosis process. The novices and experts differed in the form and use of schemas; the novices were resistant to change their schema in the face of conflicting data. Lesgold et al. (1988) state, experts "immediately begin searching for schema to guide [their] thinking…[they] didn't just accept that schema but kept trying both to test and elaborate it" (p. 319). Not only do expert radiologists seem to use schema to support the processes of assessment and diagnosis, but they also seem to produce them fairly quickly to guide the process of organizing information. In contrast, novices tend to jump to their initial answer, accepting the first diagnosis they reach.

In order to study this more in depth, Lesgold et al. employed the second experiment requiring the participants to trace x-ray features, both normal and abnormal, as they considered them in their diagnoses. What they found were novices making errors related to a failure to notice subtle perceptual details in the x-rays. Experts noticed different densities in an x-ray, relating such patterns to x-rays from past patients and diagnoses. Using their schema, experts also seem to correctly explain away irrelevant information that led to misdiagnoses by the novices. The ability of experts to critically evaluate incoming information and use it to guide continued sensemaking is described as “opportunistic” by Lesgold et al. and as crucial in medical diagnosis. In the present study, it was expected that expert aviators would similarly be found to use their schema to guide perception and sensemaking about complex and possibly ambiguous situations.

Expert ability to adapt behaviors. Research on landmine detection expertise (Staszewski, 2000; as cited in Cooke & Durso, 2008) revealed that experts use mental representations sparked from past experiences not only to aid them in pattern recognition and sensemaking, but also to adapt their behavior accordingly. Since expert landmine detection requires both human skill and technology, it is important to find where the two diverge in order to understand the techniques used. Staszewski studied the performance of two expert mine detectors to determine the strategies used by successful landmine detection experts and thus aid new training techniques. Seventy-one landmines were randomly placed within four different “lanes” and one of the lanes also included plastic mine dummies. The two participants, RR and WS, were given the AN/19 PSS-12 detection device; the same used by US forces. The devices provide an auditory signal when conducting material entered the small sensor field on the detection device. The event was video recorded to capture the participants’ view, the devices’ output and the concurrent verbal reports made by both individuals. The participants were not constrained to time limits nor methods of detection, they were only told to voice their thought processes aloud (a technique for studying expert cognitive performance), search as quickly as possible, place a poker chip as close to the middle of the located landmine as possible, attempt to minimize false alarms, and attempt to maximize landmine detection. Each participant was tested once on each of the four lanes. After completion, the participants rated their confidence in their accuracy.

Both experts performed above average; however, more interesting were the methods they used. Staszewski characterized their behavior as consistent with three goals: search, investigate, and decide. Searching consisted of sweeping over an area, listening for auditory signals from the devices while slowly changing the sweeping location to ensure overlap if a signal was not heard. The experts excelled in search because they had adapted their behavior by enhancing the sensitivity of the device by lowering the search head so their sweeps were in direct contact with the surface of the ground, not slightly above. They also did not cover large areas with fast movements; rather, they only slowly covered three-square meters at a time. This was especially important due to the variability of the auditory outputs if conductive soil was found. The participants then investigated whether the outputs from the device were reliable, or if they were simply due to conductive soil. As during search, they used small, overlapping sweeping movements to investigate the reliability of the device outputs. In addition, to aid memory of what ground had already been covered and where the device sounded, directions were spoken aloud in regards to some landmark, such as a pebble. This continued until a satisfactory, steady output was heard from the device. Then a conceptual four-point box was mentally constructed around the periphery of the auditory outputs and a 2-dimensional mental map of the device output pattern mentally envisioned within the box. By fixing the head of the device at a 30-degree angle above the ground and sweeping wider around the envisioned four – point box, the experts assessed the auditory pattern within a clearly defined perimeter and stored it as a mental map. The final goal, *decide*, involved comparing the newly produced mental map with patterns of landmine locations stored in memory from past experience. Both experts were able to make inferences about the size and shape of objects causing the device to sound. Staszewski asserts that experts and novices differ in the number of stored patterns and the ease with which the new patterns are produced and compared. Staszewski's research with RR and WS led to the development of Cognitive Engineering Based on Expert Skill (CEBES) as a new training method for landmine detection.

Once again, research on experts highlights the instrumental role of knowledge structures to store knowledge of past experiences in ways that support rapid and fluent data collection, situation assessment and response. The present study investigates the role of the knowledge structures in fast-paced aviation domains. In addition, the results of this study may suggest changes or additions that could improve the Data/Frame Sensemaking Theory.

Data/Frame Theory

A theory that addresses how people use knowledge structures to handle and make sense of complex situations is Klein's Data/Frame Theory of Sensemaking (e.g., Klein, Phillips, Rall, & Peluso, 2007; Klein, Moon & Hoffman, 2006; Sieck, Klein, Peluso, Smith & Harris, 2007). The sensemaking theory centers around the use of frames to organize incoming data. The theory builds upon Klein's earlier work on naturalistic decision-making and his development of the theory of Recognition-Primed Decision Making (RPD; e.g. Klein, Calderwood & MacGregor, 1989). RPD asserts decisions are made by recognizing familiar details of a situation. Sensemaking further elaborates by declaring activities that occur if and when details are recognized.

Frames and Mental Models. Central to the Data-Frame Theory is the knowledge organization construct, the frame. According to Klein, Phillips, Rall and Peluso (2007) a frame is "a structure for accounting for the data and guiding the search for more data, where the data are the ‘interpreted signals of events’” (p. 118). Frames serve to integrate incoming data with other elements in the environment or scenario and with past relevant experience.

Frames equate with schemas, a construct with a relatively long history in psychology. The schema construct goes back to one of the earliest references in the work of Bartlett (1932; as cited in Roediger et al. 2000), who proposed a theory about the role of the schema in memory. Bartlett conducted experiments to study memory, most notably his “War of the Ghosts” experiments. Based on his research, memories are not so much recalled as reconstructed and that when reconstructed, memories tend to be changed to better fit our cultural biases, ways of thinking about the world, and schemas. According to Bartlett, schemas represent generic knowledge about our surroundings. This generic knowledge influences new memories. He held that if incoming information does not fit a person’s schema, the individual adapts the information until it fits. The problem with using one’s own general knowledge to reconstruct a story from memory is that many details about what actually happens are replaced by generalizations based on knowledge of what usually happens, leading to memory errors.

Mental models are another knowledge structure construct with a role in Klein’s data/frame theory. Klein at al. (2007) defines mental models as “our causal understanding of the way things work” (p. 130). According to Klein at al., “they are another form that frames can take, along with stories, scripts and maps and so on. They can be stories, as when we imagine the sequence of events from stepping on a brake pedal to slowing down the velocity of our car” (p.130). Mental models are a type of frame that focuses on the dynamic relationships and interactions among elements in a scenario in order to tell a story. Mental models can be quickly configured in order to understand cause and effect relationships in dynamic scenarios.

Description of the Data/Frame theory

The conceptualization of sensemaking proposed by Klein and his colleagues (e.g., Klein, Phillips, Rall, & Peluso, 2007; e.g. see fig. 1) is their Data/Frame Theory of Sensemaking. According to this theory, in order to understand a situation, people first begin with a frame that helps shape and organize incoming data. Certain cues or anchors within the scenario are recognized by the individual in order to elicit a frame. This is where expertise and experience may have a major impact. This frame may represent a typical scenario or it may be constructed from multiple fragments of frames in order to adapt to and handle a new scenario. The relationship between data and frame is symbiotic: the established frame defines the relevant data and incoming data cause the frame to be adapted. The diagram in Figure 1 clearly displays this relationship. The right side refers to ways the data affect the frame while the left is how the frame affects the data. A unique characteristic of the sensemaking theory is the stress put on the "active" individual. Individuals are not passively absorbing information in their environment; rather, they continually assess and determine what cues and anchors are relevant and important. Klein and his colleagues describe a frame as a hypothesis about the current situation. Klein and his colleagues describe the theory as a "closed-loop transition" between explaining the data that are currently present and anticipating what data are to come. A frame allows a person to not only decide if the current data are sufficient or not, but to also project into the future what data will be needed. Individuals may engage in seeking data to add to the understanding of the situation and these data are added to the active frame. By seeking data, elaborating and questioning the frame, the individual assesses whether the frame (hypothesis) is a good fit to the data. Individuals may engage in preserving the frame, where inconsistent data are explained away, or in questioning the frame, where the frame is recognized as inconsistent with the incoming information. If a frame is no longer a good fit, reframing occurs so that frame once again fits the data.

It is important to note that, despite the cyclical appearance of the model (e.g. see fig. 1), a strict cycle does not need to be followed in order to make sense of a situation. Klein et al. (2007) stress that any place can act as the starting point of sensemaking; it simply depends on the situation.

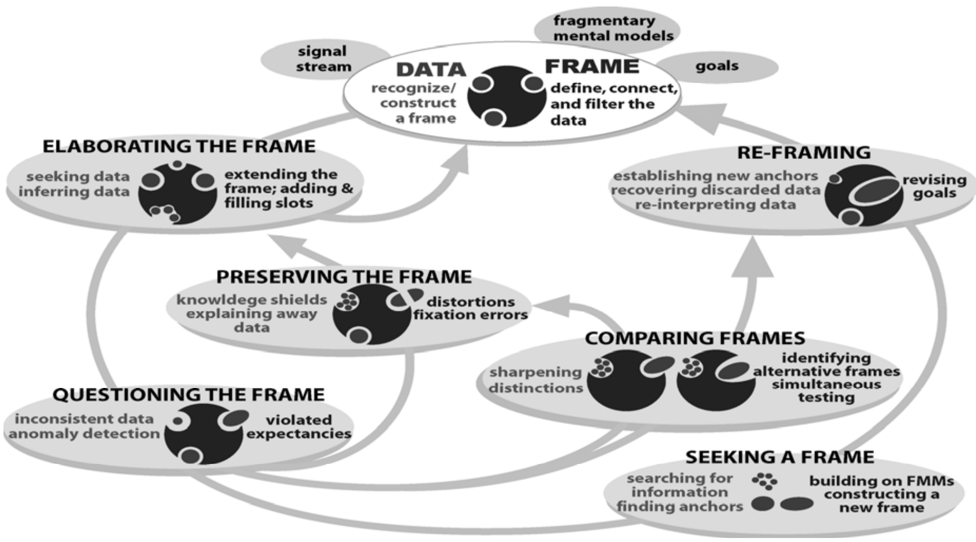

Figure 1. Data/Frame Theory of Sensemaking (2007). This figure illustrates the sensemaking activities involved in the Data/Frame Theory.

In order to dispel the notion that the model is simply “common sense,” and convey its importance to the understanding of cognition and information processing, Klein, Moon and Hoffman (2006) present five areas where the Data/Frame Theory is more than just simple common sense. First, they stress that individuals resist examining the entire situation to make sense of their current environment. They would much rather select “simple chains of cause and effect” (p. 89) relationships to assess a situation, however, this often leads to oversimplification of the situation. Secondly, the Data/Frame theory relates forming a hypothesis to establishing a frame. It is important that the frame be chosen early in order to facilitate deliberate testing of its appropriateness and so that incoming data can be evaluated in a meaningful context. Thirdly, feedback is crucial in decision-making and especially when it allows the person to understand what about the sensemaking and decision-making was wrong or right and not just whether the decision itself was wrong or right. Klein et al. (2006) assert that the value of valid feedback tends not to be adequately appreciated; as seen in Figure 1, all sensemaking activities can benefit from feedback. Fourthly, sensemaking cannot be treated as a skill where every step of the process is separate and can be taught. Sensemaking is a complex, multifaceted, process that cannot be pulled apart into consecutive steps or other separable components. Finally, sensemaking is not simply about confirming or disconfirming information. Sensemaking is also about being able to shift attention to a better fitting frame when the accuracy of a frame is questioned.

The importance of Klein's sensemaking model to this research cannot be stressed enough, thus it will be described further by walking through the activities shown in Figure 1. Examples of research questions that are addressed by the current study will be embedded throughout the model description.

An individual will usually notice and choose a frame based on three or four cues, which Klein refers to as anchors. Klein et al. (2007) point out that the environment, individual characteristics, and available information will additionally influence the frame that is chosen. Once a frame has been chosen, it is a source of expectations that the individual uses to actively seek information that relates to the frame. This additional information supports elaboration of the frame where slots may be added and filled with matching data from the environment and where inferences may be made. In addition, existing frame slots are filled as key data about the environment are perceived.

Information that does not map to (or fit) the frame may be ignored; if given attention, this unexpected information may cause the individual to question the frame. The expectancies created by the frame may be recognized as violated and an adjustment to the frame or a switch to a different frame may occur. For example, this may occur when a pilot switches from a landing frame to a "go-around" frame when cues begin to indicate a successful landing may not be possible.

If the individual is preserving a frame, he or she is explaining away data that conflicts with the chosen frame instead of adapting the frame or choosing a new one to accommodate the data. Sometimes individuals need to compare an opposing frame to the originally chosen frame. This can aid in breaking free of fixation on a given frame and is widely seen in medical diagnosis where symptoms are evaluated in the context of different possible diseases (i.e., in these frames) until the correct diagnosis is realized and treatment can be given. Klein, Pliske, Crandall and Woods (2005) describe the inability of inexperienced nurses to arrive at a correct diagnosis and attribute this to an appropriate mental model, i.e., frame. When the same cues were available, the inexperienced nurses only used initial surface symptoms to diagnose an ill infant, instead of comparing all of the symptoms to past cases. The nurses fixated on the surface symptoms instead of gathering all available information and comparing it to past knowledge.

To properly interpret new data that are incongruous with the active frame, reframing must occur; preserving the frame stops and a new frame is chosen. Previously discarded data may now fit the new frame and goals may need to be re-evaluated. If the data do not fit the new frame or the frame cannot explain the data adequately, another frame will be sought. Once again, anchors come into play; however this time, they likely are those cues that triggered recognition of the need for a new frame.

Challenging Aviation Operations

Complex systems are characterized by elements that are “dynamic, simultaneous, parallel, and organic (evolving, emerging) rather than governed by simple cause and effect” (Feltovich, Hoffman, Woods, & Roesler, 2004, p. 91). Aviation is considered a complex domain because multiple events that are highly interactive are occurring at once while the pilot flies the aircraft. Furthermore, UAV operations are seen as highly complex for that same reason; additionally, UAS pilots do not have the multiple rich sensory inputs experienced by other pilots to increase the level of awareness during flight. Operators cannot smell or hear the engine to be warned of complications; nor are they tactilely stimulated to support awareness and problem detection, e.g., a drift from course into weather or turbulence (e.g., Williams, 2008). The environment is seen as dense because of the number of things occurring at once and extent of changing details. Operators must rely on what they can see through a limited camera view. Predator UAS pilots are provided with a 30-degree view lacking depth perception and peripheral vision (Pestana, 2009).

Military operations are an example of highly complex scenarios. While the pilot follows standard operations and procedures, other variables can alter the goals of the mission forcing the pilot to quickly adjust.

Qualitative Research

Three types of validity were considered important to this qualitative research: descriptive validity, interpretive validity and theoretical validity (Johnson, 1997). Descriptive validity refers to, "the factual accuracy of the account as reported by the qualitative researcher" (p.284). In the present research, descriptive validity was addressed by two interviewers conducting the interviews and two coders coding the raw transcribed data. Interpretive validity refers to, "the degree that the participants' viewpoints, thoughts, intentions, and experiences are accurately understood and reported by the qualitative researcher" (p.284). Interpretive validity was also addressed by two coders coding the raw data of the transcribed interviews. Theoretical validity refers to, "the degree that the participants' viewpoints, thoughts, intentions, and experiences are accurately understood and reported by the qualitative researcher" (p. 285). Theoretical validity may be more difficult to obtain than descriptive and interpretive because it deals with the how and why of events which can be ambiguous. The current research on cognitive information processing has been studied and theorized by many psychologists, however per the results, Klein's data/frame theory clarifies this processing with military aviation complexity. The researchers viewed demonstrations of UAV operations and spoke with UAV subject matter experts (SMEs) in the domain aiding descriptive and interpretive validity. Also, two coders coded the interview data chunks in an attempt to gain investigator triangulation, where multiple investigators must collect and analyze the data, to minimize bias throughout the consideration of multiple perspectives.

This research follows a design similar to that used by Klein and Jarosz (2011). Klein and Jarosz studied insights, or "discontinuous discoveries" (p. 335), in the natural environment to understand how insights develop. They stress the explorative nature of their study due to the innovativeness and the ability for future studies to build off their findings. Klein and Jarosz collected 120 incidents from interviews, observations, personal events and other media such as books, newspapers and magazine articles. They then coded the incidents using fourteen features such as whether or not the individual made a connection between pieces of information or if they attempted to explain away or explore a contradiction in their thinking. Two coders independently coded the data, and then, together, reevaluated and adjusted the codes. The intentions of Klein and Jarosz were similar to the present research in wanting to explore the cognitive functions of individuals versus testing a hypothesis. Finally, they found most insights originated from connections and contradictions and not an attempt to explain away the contradicting evidence therefore insights occur when a person shifts their attention to discover how things happen in their current environment. Individuals use insights to revisit or reframe their current frame in the face of new information.

Research Approach

This research approach followed Klein et al.'s critical decision method (CDM; e.g., Flanagan, 1954; Klein, Calderwood, & MacGregor, 1989), which is a semi-structured interview method using the recounting of past incidents to elicit knowledge from experts during challenging events within their domain. Challenging incidents are a rich source of data about cognitive work because they tend to require a wider variety of attentional strategies, the processing of a greater amount of information, more difficult decisions, and so forth. They are also used because they are more memorable to the individual, and thus the interviewee is able to recount actual details of actual events from memory. This reduces the tendency of interviewees to broadly state how they think they typically do something, a type of account that is more vulnerable to inaccuracy. Concerning validity, CDM validity can be difficult to judge because the exact circumstances cannot be recreated and once the event is related, the individual's memory of such event is forever altered in their memory.

Overview

While the expert domains described above in the review of literature can be intense, they are not exactly like military aviation, which can be very demanding and time pressured. Military aviation and UAS events used in the present research are characterized by the lack of proprioceptive sensations, incomplete data and time-pressured decision making as discussed earlier.

In this research effort, pilot interviews were analyzed using an analysis framework based on Klein's sensemaking model in an effort to obtain an improved understanding of professionals' ability to handle large amounts of incoming data. The proposed research follows the methodological philosophy expressed by Pepperberg (2008). Pepperberg agrees for the importance of observing and learning before hypothesizing and, even then, she argues, the "truly interesting questions" often don't translate into traditional testable hypotheses. She believes the emphasis on testable hypotheses leads to scientists attempting to "prove" their point instead of trying to further knowledge and understanding. Dreyfus and Dreyfus (1980) extend this line of argument or logic stating, "descriptive data, while precise and replicable, might seem to lack the objectivity and quantifiability produced by controlled laboratory experiments. However, there is a long tradition in psychology and philosophy of suspicion of the significance of experimental results produced by restricting experiments to precisely controlled but highly artificial situations" (p. 2).

Research Questions

The overarching goals of this research were to assess professional pilots in military high performance vehicles to understand how and how much they are able to do versus the limits of working memory, contribute to expertise literature regarding characteristics and abilities of experts, and finally to evaluate Klein's data/frame theory of sensemaking. In addition, specific questions that were investigated include the following:

1. What types of sensemaking activities are used the most frequently in military aviation?
2. Sieck et al. (2007) assert experts use three to four cues to elicit a frame. Are three to four cues sufficient to trigger a change?
3. How does Klein's sensemaking theory compare with the sensemaking activity patterns found in the data of UAS and manned pilots?
4. Do the patterns found in the data suggest any additions to the theory?
5. Under what conditions do experts tend to be more likely to question a frame in the face of contradictory data? When do they tend to be more likely to preserve the frame?

Method

Participants

Four experienced pilots of high performance aircraft (to be referred to as Pilot A, B, C & D) participated. Pilots' ages ranged from 35 to 50 years old. The pilots' flying experience ranged from 0 hours to 4500 hours in unmanned aerial systems (*M* = 1,355 hours) and 1914 hours to 5150 hours in traditional aircraft (*M* = 2,823 hours; see Table 1).

Table 1

Participant Flight Hours

	Pilot A	**Pilot B**	**Pilot C**	**Pilot D**
Flying Experience (hrs)	UAS: 200 Traditional: 1915	UAS: 0 Traditional 5150	UAS: 720 Traditional: 2250	UAS: 4500 Traditional: 1980

Each pilot completed a biographical questionnaire about his relevant training and experience (see Appendix A) prior to participating in an interview lasting one to two hours. The pilots were also asked for permission to audio tape their interviews and were additionally asked to read and sign a consent form explaining their rights as research participants.

Although a sample size of four may be considered low for quantitative research, small sample sizes are common in qualitative research. Validity concerns associated with low sample sizes and the interpretation of qualitative data are addressed in this study using strategies listed in Table 2. In the present study, a sample size of four was able to shed light on sensemaking strategies used to detect, assess, and respond to challenging flight events and scenarios and to compare the strategies with Klein's data/frame sensemaking theory.

Table 2

Johnson's Strategies to Gain Validity with Qualitative Research

Strategy	Definition	Current Research
Low Inference Descriptors	The use of description phrased very close to the participants' accounts and researchers' field notes. Verbatims (i.e. direct quotations) are a commonly used type of low inference descriptors.	Verbatim – direct quotes (raw data) of the participants' interviews used when coded by the coders
Low Inference Descriptors	The use of multiple investigators (i.e. multiple researchers) in collecting and interpreting data.	At least two researchers present when interviews were conducted
Theory Triangulation	The use of multiple theories and perspectives to help interpret and explain the data.	Multiple expert vs. novice theories and research used to explain behavior.
Peer Review	Discussion of the researcher's interpretations and conclusions with other people. This includes discussion with a "disinterested peer" (e.g. with another researcher not directly involved.)	Discussion with SMEs prevalent with no benefit gained from research, discussion with committee and presentations at conferences.
Pattern Matching	Predicting a series of results that form a "pattern" and then determining the degree to which the actual results fit the predicted pattern.	Pattern in activities of sensemaking model.

Data Collection

Each CDM interview was jointly conducted by two to three researchers. The interviews (with Pilot C) were conducted in conference rooms with three researchers and the pilots seated around a conference table. One interview was conducted over the phone by three researchers

(Pilot A). The other interviews were conducted outdoors. One of the two (Pilot B's) was conducted by two researchers who sat on benches facing toward the pilot at a small round patio table. The other (Pilot D's) was conducted at an outdoor bench by two researchers who sat angled toward the pilot, one on the bench and the other on the ground next to the bench.

In each interview, the pilot was asked to think of a past difficult, and therefore memorable, event that was complex, fast-paced and involved the handling of high amounts of information. The pilots were asked to recount the details from the past event and to try to describe what they were perceiving, thinking, and doing as they talked through the event (See interview protocol in Appendix B). The researchers listened and took notes while occasionally asking for clarification when needed. After the pilot finished talking through the event, the researchers went back through the event with the pilot. During this second run through, the pilot was asked to correct, clarify, and elaborate on details of the account, especially those details about decision making, information they were seeking, ignoring or anticipating and how they were receiving such information. Time permitting, a second memorable event was chosen and recounted using the same protocol. All CDM interviews were audio taped using two recorders and each recording was transcribed.

Data Analysis

Transcribed interviews were segmented into data chunks, each consisting of a single idea or concept. The order of the data chunks was maintained for coding so that the context of each event was maintained.

Coders. The interview chunks were coded by two coders. Coders were the author and an educator in Human Factors. Both were knowledgeable about Klein's sensemaking theory, human performance theory that emphasizes control loops (e.g., Hollnagel & Woods, 2005;

Worm, 1999), and factors that affect the validity of qualitative research (e.g., Johnson, 1997). Coders worked to obtain consistency in their coding by iteratively coding small sets of data chunks, then reviewing and discussion code choices. This process led to changes in coding practices and also to changes in codes.

Codes. The codes used to categorize and assess the interview data chunks represent sensemaking activities specified by Klein's sensemaking theory. These codes, shown in Table 3, were derived by the principal investigator and educator in Human Factors. In addition to the sensemaking codes, a second set of codes was derived from Hollnagel's (2002) Contextual Control Model (COCOM). These codes, shown in Table 4 and Appendix C, allowed the coding analysis to capture contextual factors that influence information processing attentional requirements, such as time pressure, clarity of outcome feedback, and understanding of the relationships and dynamics that influence the outcome feedback. If, during the coding process, codes did not map to all data, code adaptations and additions were made to improve the fit of the codes to the data.

Table 3

Codes Derived From Klein's Data/Frame Theory of Sensemaking.

Codes	**Codes Definition**
Define a Frame (DF)	- Reference goals, constraints, or structural characteristics known about the current situation, i.e., captured in the active frame.
Seek or choose a frame (SF) - **Use anchor(s) to elicit frame** - **Use experience and context to elicit frame** (not specified by Sieck	- Use cues or pieces of data to elicit a frame. (Cues and data used to elicit a frame are considered anchors.). - Use the context of current activities and conditions combined with knowledge of procedures and patterns to elicit a frame that anticipates the next situation or goal.

et al.)	
Confirm and elaborate the frame (CEF) **- Seek data** **- Draw inferences and conclusions that extend the frame** **- Fill data slots in frame** **- Add slots to the frame** **- Combine fragments of frames** **- Use pre-existing knowledge to fill data slots**	- Take effortful actions to obtain data (versus just use what is given via communications or display); assess understanding of situation to determine whether more data are needed. - Use information to draw inferences and conclusions. - Use newly received information. - Reorganize the need for a piece or type of information not previously considered relevant or useful. - When situations have not been encountered previously or vary in fundamental ways each time they're encountered, a single useful frame may not exist and a person may draw from multiple fragments of frames to support sensemaking. - Use knowledge one already has about the type of event or situation that is ongoing.
Preserve the frame (PF)	- Explain away, minimize the importance of, ignore, or distort data that does not fit the current chosen frame.
Question the frame (QF) **- Question the quality** **- Test the frame** **- Recognize a Violated expectancy**	- Question whether or not the incoming data fits the active frame. - Seek confirmation of data from a second or third source. - Test frame by comparing the results of actions and interactions with frame-based predictions. - Notice that incoming information does not fit predictions derived from the active frame, data slots, or expected slot values and, consequently, question the active frame's appropriateness.
Compare the frame with alternative frames	- Identify alternative frames, collect evidence to evaluate alternative frames, or directly test the most likely alternative frame (e.g., by taking actions and assessing whether the result is what's predicted for a given frame).

Reframe - **Adapt the active frame** - **Elicit or construct a new frame**	- Frame adaptations can involve establishing new anchors, recognizing previously discarded data as relevant, or revising goals. - Eliciting or constructing a new frame supports sensemaking recovery, a term Seick et al. use to describe the recognition of a situation for what it really is, versus, for example, what a perceiver expected or wanted it to be.

Table 4

Worm's Adaptation of Hollnagel's COCOM Control Modes and Characteristics (1999; derived from Hollnagel and Woods, 2005)

	Main Characteristics					
Control Mode	**Subjective-ly available time**	**Familiari-ty of situation**	**Level of attention**	**Number of goals**	**Choice of next action**	**Evaluation of outcome**
Strategic	Abundant	Routine or novel	Medium - high	Several	Prediction based	Elaborate
Tactical (Attended)	Limited, but adequate	Routine, but not quite – or task is very important	Medium – high	Several, but limited	Plan based	Normal details
Tactical (Unattend-ed)	More than adequate	Very familiar or routine- or almost boring	Low	Several, but limited	Associa-tion based	Perfunctory
Opportunis-tic	Short or inadequate	Vaguely familiar but not fully recognized	High	One or two (compet-ing)	Associa-tion based	Concrete
Scrambled	Very limited	Situation not	Full - hyperatten-	One	Random	Rudimen-tary

		recognized	tion			

Coding. The coders only coded data chunks related to the past events recounted by the pilots; other data in the transcripts were disregarded. Data chunks were coded in sequence, from the beginning to the end of each event transcript, so that the context in which each chunk occurs was not lost. An example is provided in Appendix D. Data chunks were first decided by the author and then discussed with the second coder. The chunks were decided by the pilot's account of an idea and/or action. If multiple actions were involved in one idea, all were separated to ensure proper recognition was given to the amount of tasks occurring. Once a total of 718 chunks were decided upon, each coder coded individually. After initial codes were completed, both coders met to discuss and review to reach a final, reconciled code. The initial interview, Pilot A, 72.06% of the interview was reviewed together, the highest percentage to ensure the coders were in agreement on the coding method. For Pilot B, 61.81% of the interview was reviewed together; for Pilot C, 40.32% of the interview was reviewed together and finally, for Pilot D, 71.82% of the interview was reviewed together. Overall, the coders reviewed 54.97% of the data chunks together. The primary researcher reviewed the remaining codes independently to decide the final reconciled code. If a large discrepancy was discovered, the primary researched discussed with the other coder on a case-by-case basis.

Coding reliability. To assess the reliability of the coding, the coding results from the two coders (including the author) were compared by calculating Cohen's kappa; suitable for coding regarding behavior using nominal scales (e.g. Cohen, 1960; Lombard, 2010). In order to use Cohen's kappa, the data must be independent, nominal and the judges operate independently. The first 50 chunks of the four interviews were submitted to a reliability analysis. After analyzing 300 chunks, 200 chunks and 120 chunks were also analyzed to determine if a stable agreement was met. The Cohen's kappa for 200 chunks was compared with the Cohen's kappa for 120 chunks to gauge the reliability of the 300 chunk analysis. To further assess validity, 25 random chunks of the four interviews were submitted to a reliability analysis. This assessment accounted for the possible confound of order of data chunks within the interview; for example more detail may have been relayed in the middle of the interview versus the descriptive beginning. A kappa of 0.61 and a correlation of .80 (Landis and Koch, 1977) or higher was viewed as indicative of a reliable, or substantial, coding process. Table 5 displays Landis and Koch's values of indicative reliable coding. Comparatively, Klein and Jarosz (2011) used Banerjee, Capozzoli, McSweeney and Sinha's (1999) correlation values; less than 0.40 were considered poor agreement and kappa values between 0.40 and 0.75 were considered fair to good agreement (p. 430). Reliability statistics were also calculated. This statistic was calculated using the Statistical Package for Social Sciences (SPSS).

Table 5

Landis and Koch's Kappa Strength of Agreement

Kappa Statistic	**Strength of Agreement**
< 0.00	Poor
0.00 – 0.21	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost Perfect

Results and Discussion

Reliability

The overall interrater agreement for the sensemaking codes (i.e., codes derived from the Data/Frame Theory of Sensemaking) was 35.7% for the initial independent coding of 300 data chunks (the first seventy-five chunks of each interview transcript), 42.5% for the first 200 data chunks and 52.5% for the first 120 data chunks. After the coders' codes were reconciled, the interrater agreement was 84.3%, 89.5% and 85.8% respectively (See Table 6). Cohen's kappa coefficient was .288 for 300 data chunks, .357 for 200 data chunks and .461 for 120 chunks. According to Landis and Koch (1977), these fall into a range of values of 0.21 to 0.40 that represent a fair level of agreement. After the coders' codes were reconciled, the kappa coefficients increased to .823, .881 and .837. The kappa coefficients are shown in Table 6. The coders then reviewed and discussed transcript chunks on which they disagreed in order to reach a 98% reconciled agreement.

A factor affecting to the kappa value and percent agreement prior to code reconciliation is the fact that the coders were refining the codes as they coded. The codes, Background Information and Pre-Existing Knowledge, for example, initially were used inconsistently and almost interchangeably by the coders. Background information refers to information that helps set the stage for the event to be described but was not used during the described event. Pre-existing knowledge is information that used during the event being conveyed. The coders initially experienced difficulty differentiating the two codes due to ambiguity in their initial definitions. This was resolved during the coding process by discussing and comparing the individuals' use of each of the codes.

The overall interrater agreement for use of the COCOM codes was 84.7% for the initial independent coding of 300 data chunks; 85.5% for 200 data chunks and 89.2% for 120 data chunks. After codes were reconciled, the interrater agreement was 98%, 97.5% and 97.5% (See Table 7). Cohen's kappa coefficient was .373 for 300 data chunks, .377 for 200 data chunks and .396 for 120 chunks; again representing a fair level of agreement. When reconciled, the kappa coefficient increased to .916, .891 and .848 (See Table 7).

A factor contributing to the high agreement post - reconciliation was likely the clear definitions of codes and clear distinctions between them. The definitions were proposed by Hollnagel (2002) and were not altered by the coders. The initial purpose of including the COCOM model was to assess the workload and the amount of information experts can handle; however, this will instead be pursued in a future analysis effort. For the evaluation of aviation sensemaking, the use of the COCOM codes shed light on when action in the events described tended to be tactical and attentionally demanding rather than strategic, opportunistic, or scrambled. The other control mode found in the data was the strategic control mode, where the individual uses more than just what is in front of him or her on the displays, i.e., more than just filling slots with incoming information; rather, the individual relies on their experiences to anticipate what behaviors are needed in the current situation.

The codes describing the nature of time pressure on the pilots' behavior, i.e., whether their performance is task-driven or self-paced, were also not included in the present analysis. As with the COCOM codes, these codes will be considered in a future analysis that focuses on pilots' workload.

Table 6

Cohen's Kappa Correlation for Initial and Reconciled Sensemaking and COCOM Codes

	Sensemaking Codes				**COCOM Codes**		
	100	**120**	**200**	**300**	**120**	**200**	**300**
Initial	.288	.461	.357	.288	.396	.377	.373
Reconciled	.930	.837	.881	.823	.848	.891	.916

Table 7

Percent Agreement for Initial and Reconciled Sensemaking and COCOM Codes

	Sensemaking Codes				**COCOM Codes**		
	100	**120**	**200**	**300**	**120**	**200**	**300**
Initial	36.0%	52.5%	42.5%	35.7%	89.2%	85.5%	84.7%
Reconciled	84.1%	85.8%	89.5%	84.3%	97.5%	97.5%	98.0%

After evaluating the above Cohen's kappa and percent agreement of 300, 200 and 120 data chunks, it was decided that the data chunks chosen may not accurately capture the variety of the data set. To assess whether a randomly chosen set of data chunks would produce other results, twenty-five data chunks from each interview were randomly chosen. The overall interrater agreement for the sensemaking codes was 36% for the initial independent coding of 100 data chunks randomly chosen; the same as for 300 chunks. Cohen's kappa coefficient was .288 for 100 data chunks, the same as for 300 chunks and a fair level of agreement. The Cohen's kappa was .930 once reconciled, which is similar to the original reconciled kappas.

Events Collected

The events recounted in the critical event interviews are presented in Table 8. Pilot A described difficulties associated with trying to maintain a tight orbit under high winds while flying a mid-sized UAS. He also described a second event characterized by the difficulties associated with landing when an engine failure has occurred. One of Pilot B's events involved responding to ground fire. He also described a second event in which he ran into difficulty during a routine requalification flight. Pilot C discussed an engine failure event and the difficulties associated with differences between crew and mission control procedures in responding to the engine failure. During the event, Pilot C dealt with engine, fuel and weather issues. Finally, Pilot D's event involved training a novice UAS pilot. During the training flight, they struggled to keep separation from high terrain, shifting winds and low runway visibility.

Table 8

Events Extracted from Interviews

Pilot	**Event**
A	Orbiting a UAS in high winds
A	UAS Engine failure
B	Flying helicopter while receiving enemy fire from the ground
B	Completing a helicopter requalification flight; accidentally used the wrong approach plate. An approach plate is a graphic document tool used by pilots to aid them during instrument approaches
C	Engine failure followed by unexpected micromanagement by squadron personnel on the ground during inclement weather
D	Instructing novice during live flight of UAS with impaired access to flight controls

To give the reader a better idea of what the events involved, sequences of key pilot activities described in each are displayed in Table 9.

Table 9

Sequences of Key Event Activities

Partici-pant/Event	**Initial Frame(s)**	**1st Phase**	**2nd Phase**	**3rd Phase**	**4th Phase**	**5th Phase**	**6th Phase**	**7th Phase**
Pilot A – Orbiting in high winds	Fly orbits within tight boundary	Orbit in high winds						
Pilot A – landing with and engine failure	Experience an engine failure	Complete emergency procedures	Establish glide	Establish basic traffic pattern base to final leg	Located destination point on airfield	Conduct an 180° turn	Monitor altitude and distance to airfield	Check and account for winds
Pilot B – Flying in hostile territory	Standard Night Flight Procedure	Detect and respond to enemy fire	Detect and respond to falling altitude					
Pilot B – Requalification flight	Determine flight goals	Fly to destination	Experience series of incongruence	Conduct approach for landing	Recognize and Respond to approach error	Pull up back to VHF Omni Range (VOR) to join Instrustrument Flight Rules (IFR)		
Pilot C – Engine failure during routine event	Begin routine flight	Experience an engine failure	Command personnel	Follow directions of com-	Dump fuel	Noticelowering cloud	Decide they can-	Conduct landing

			intervene in pilots' response to engine failure	mand person-nel		deck	not divert	with an inop-era-tive en-gine
Pilot D - Training	Train novice to fly UAS	Ap-proach inclem-ent weather	Tempo-rarily lost link	Train tech-niques to handle lost link event	Miss the landing ap-proach and conduct go-around			

Patterns Within the Data

After coding the data using the sensemaking theory codes, the coded data were reviewed to find patterns in the pilots' sensemaking across the six events. Patterns identified during the review were analyzed to see if they were reliably supported by the data. Before walking through the chosen event to relay details, each participant described the event's setting and goals. This description served to define the frame. The following patterns were reliably supported by the data:

- **Pattern 1**: Experts relied predominantly on knowledge already in their event frame (coded as pre-existing knowledge), versus incoming data (coded as fill slot of frame), to make sense of their situation.
- **Pattern 2**: There was a tendency for the seeking of data (coded as seek data) to co-occur with the drawing of inferences (coded as extend the frame).
- **Pattern 3**: Three of the four experts seemed to perform sensemaking activities associated with reframing in a sequential manner. This is demonstrated by the pattern in behavior

sequences of first recognizing a cue violating their active frame, then evaluating the cue before diagnosing the situation and then finally, reframing.

These three patterns will be described in turn below.

Pattern 1. The first finding to be discussed is the tendency for experts to rely on pre-existing knowledge already embedded in their frame, versus new incoming information, to make sense of the situation. Out of a total of 718 data chunks, 21.03% (151 instances) were coded as use of pre-existing knowledge; the highest frequency out of all the codes. This high frequency supports the notion that the experts relied on pre-existing knowledge more than any information in their environment. However, to the extent that the use of pre-existing knowledge did not fully support sensemaking, the experts filled slots of their frames with information they obtained during the event. The second highest frequency of all the codes was fill slots with a frequency of 11.56% (83 instances).

An example of these codes can be seen in Pilot D's training event. Pilot D used pre-existing knowledge of the difficulties involved in UAS training, noting, for example that "another challenge of this system of pilot in-the-loop is that there are no conventional controls as with manned aircraft where you're able to stay on the controls." This knowledge allows Pilot D to anticipate difficulties that may arise while training a novice and maintaining safety of flight. Pilot D had to further make sense of the event by filling slots with observable event information to address the severity of the flight. An example of Pilot D filling slots occurs when the weather is observed, for example. He discussed this as, "proceeding out to the GCS, noting the weather was, on our weather brief, was fairly gusty cross winds as they are out in the ranges."

Pattern 1 implications for theory. The heavy use of pre-existing knowledge supports the idea that sensemaking is driven by a framework encapsulating past experiences (i.e., by frames). That is, this research suggests that experts in complex, time-pressured aviation domains rely more on their knowledge structures, frames or schemas, than on the incoming data to support sensemaking. This is supported by the frequency with which the codes are used, both overall and during individual events.

Pattern 2. The second pattern assessed the tendency for pilots to seek additional data to help with drawing inferences and conclusions that extend the frame. The pilots were more likely to "fill slots" of their frames with incoming data than they were to actively seek data (11.56% versus 2.92% of the data chunks, respectively). It is suggested that pilots mainly actively sought data when the frame they were using was not completely adequate for guiding performance and behaviors in a given situation. To evaluate this possibility, the frequency with which chunks coded as "seek data" were followed by chunks coded as "extend frame" was assessed. Pilots engaged in seeking data 2.92% of the time with twenty-one instances in 718 data chunks. Their data were coded as extending the frame 4.32% of the time with thirty-one instances. In order to assess if these activities co-occurred, the events were analyzed to determine how many data chunks separated the activities of seeking data before extending the frame. Column 4 of Table 10 shows the frequency with which seeking data occurred shortly before extending the frame and the number of chunks to separate them in each event.

Table 10

Support for the Relationship Between Seeking Data and Extending the Frame

Participant/Event	**Seek Data**	**Extend the Frame**	**Seek before Extend?**
Pilot A – Orbiting in high winds	None: - Pilot did not engage in seeking data	Six instances to: - Determine correct orbit pattern/path - Adjust for crabbing to maintain heading - Maneuver to give best view of target	No instances of "seek data"
Pilot A – Landing with an engine failure	Nine instances to: - Monitor airspeed, rate of descent, winds and relation to airfield	Five instances to: - Expedite descent to establish traffic pattern base to final leg. - Calculate glide ratio	Three instances of the fourteen involving seeking and/or extending were: - One to four data chunks apart
Pilot B – flying under enemy fire; losing altitude	One instance to: - Position gunner on target	None: - Pilot did not extend the frame	No
Pilot B – keep gunners on target	Two instances to: - Position gunner on target - Determine meaning of light	One instance to: - Calculate ability to shoot back	Two instances of the three involving seeking and/or extending were: - Six to nine data chunks apart
Pilot B – Completing qualification course	None: - Pilot did not seek data	None: - Pilot did not extend the frame	No
Pilot C – Engine failure response disagreement	Seven instances to: - Assess health of aircraft - Determine weather - Assess where to	Eight instances to: - Determine pilot cannot divert - Assess how long they can go-around	Six instances of the fifteen involving seeking and/or extending were: - One to two data chunks

	land - Determine location of aircraft in relation to runway	- Determine if they are lined up	apart
Pilot D - Training	Two instances to: - Anticipate and determine if novice is making mis-takes (e.g., if speed or altitude is off)	Ten instances to: - Determine the difficulty of flight/event - Assess the need for intervening (i.e., corrections) - Compare what the student is doing to what Pilot D would do - Reprogram the aircraft to new configurations - Determine how much verbal instruction is needed - Knowledge to assess data link	Two instances of the twelve involving seeking and/or extending were: - Four to five data chunks apart

Seeking data did tend to precede extending the frame. There were twenty-one instances of seeking data and thirty instances of extending the frame. Four events together included twenty cases of seeking data before extending the frame. The two events that did not include this pattern included Pilot A orbiting in high winds, (extended the frame without first seeking data) and Pilot B flying under enemy fire; (sought data but did not extend the frame).

Pattern 2 implications for theory. Pattern 2 is consistent with the sensemaking model. It does, however, suggest that the activities and dynamics described in the model could be further refined to better match real-world sensemaking. In particular, support for pattern 2 suggests a tendency for people to rely on available information rather than to seek information and that when they do seek information, it may tend to be for purpose of finding a frame that is not completely adequate for the situation at hand. The model does not suggest a specific pattern, however, with the current research, the individuals were seeking data before extending their frame, thus suggesting a sequential pattern between the two activities not stressed, but present, within the model.

Pattern 3. The third pattern is the tendency for pilots to reframe in response to a cue that they know, based on past experience or training, can signify a need to "reframe." Conversely, within this pattern, if a cue or the changed situation it represents is not part of the pilots' training or experience set, the pilot will tend to "preserve the frame." Table 11 breaks down each case of a cue in violation with the current frame. Once a pilot detects a cue in violation, she may "reframe," or replace the existing frame with one suited to the situation. If a pilot does not reframe, he would preserve the frame. Table 11 breaks down each case of a cue violation across the six events. Specifically, it indicates: the event, whether or not the individual reframed or preserved the frame and what detected cues were in conflict with the original frame. The table also provides information on the pilot's evaluation of the cue and whether or not the cue in violation could be anticipated or is something the pilot was prepared for. Reframing was done 1.25% of the time, i.e., found in nine out of 718 data chunks. "Preserving the Frame" was used to code 3.06% or twenty-two instances out of 718 data chunks.

Table 11

Responses to Cues that Conflict with Active Frame

Participant/Event	Reframe or Preserve the Frame	Cue(s) in Violation	Timeline of reframing: immediate vs. delayed response to cue	Evaluation of Cue	Pilot has warning or preparation
Pilot A – Landing in high winds and an engine failure	Reframe: Nominal flight conditions change to emergency flight conditions.	Cue not stated outright.	Immediate	Transition to emergency precedes start of event description.	Yes; pilots are taught to follow checklist procedures when landing with an engine failure.
Pilot B – flying under enemy fire; losing altitude	Reframe: Nominal night flight conditions change to high stress, under fire conditions.	1st cue; white light, sinking too fast 2nd cue; city buildings	Delayed Pilot questioned incoming data	Pilot recognized a violated expectancy and then evaluated to diagnose the cue in violation	Yes; pilots flying in hostile territory anticipate possibilities of receiving fire from enemy
Pilot B – Completing qualification course	Preserve the frame: Easy requalification flight complicated by approach to wrong airport.	1st cue; VHF Omni Flight Range (VOR) unexpected frequency 2nd cue; Airport not in sight	Delayed Pilot explained away data	Pilot recognized the violating cue but explained it away	No; pilots do not anticipate attempting wrong approaches when landing
Pilot C – Engine failure	Reframe: Nominal training flight conditions change to emergency	1st cue; Thump 2nd cue; Alarm light configuration	Immediate Pilot knew to return to base when engine	Pilot recognized a violated expectancy and then evaluated to	Yes; pilots are trained to handle engine failures with standard

	flight conditions.		failure occurred	diagnose the cue in violation.	operation procedures (SOPs)
Pilot C – Redirected by exercise leadership	Preserve the frame: Trained response to engine failure is disrupted and new response is forced on crew.	1st cue: pilot receives radio call to go around and dump fuel	Delayed	Pilot did not want to follow request. Preserved frame as long as he could.	No; pilots do not expect to be interrupted while completing normal emergency procedure.
Pilot C – Inclement weather; low fuel	Reframe: Nominal weather conditions replaced by dropping cloud ceiling.	1st cue; Ground controller calls in weather	Immediate Pilot recognized weather as an issue	Pilot did recognize violated expectancies, could not divert but fluently followed directions to land.	Yes; pilots taught to handle inclement weather.
Pilot D – teaching student; missed approach; cannot see runway to land	Preserve the frame: Landing becomes a missed approach and go-around.	1st cue; unable to see runway	Immediate	Pilot recognized they couldn't see the runway, however diagnosis was to use instruments and go-around.	Yes; instructors anticipate actions of novice pilots and are taught to land relying on instruments.

Pattern 3 implications for theory. The data suggests a sequential flow of sensemaking activities that lead to reframing. This suggests that the pilots performed sensemaking activities in a more organized, sequential manner than proposed by Klein's sensemaking theory, which says reframing follows a less predictable set of activities. As seen in Column 4, only two out of the seven events did not involve first recognizing a violated expectancy before reframing. This supports the pattern of an organized flow because more often than not, the pilots first recognized a violated expectancy, evaluated and diagnosed this expectancy and then reframed. However, the number of cues that triggered reframing ranged from one to three cues, which is consistent with Klein's sensemaking theory.

Evaluating the Sensemaking Model Activities

When interview chunks could not be coded using the existing set of codes, additional sensemaking activity codes were added. These codes represented sensemaking activities that were not initially derived from the data/frame theory. Those codes included:

- Evaluating the cue in violation
- Diagnosing the cue in violation
- Elaboration
- External questioning causing preserving of the frame
- Assessing workload

The sensemaking model does not specifically include the exact terms above, however the data suggests the current sensemaking model captures all of the sensemaking activities. The authors used the above codes to analyze the data, but due to their similar nature to sensemaking activities described by Klein's model, no new sensemaking activities are suggested for the model. Therefore, this research supports the sensemaking model as a comprehensive conceptualization of sensemaking.

Evidence of adding slots to frames or combining fragments of frames, activities described by the sensemaking model, were not seen. It is possible, however, that the pilots may have been adding slots and combining fragments of frames because the activities can be difficult to detect.

General Findings

In two events the pilot was unable to anticipate change that called for reframing; that is, the pilots were slow to recognize and adapt to their situation. Pilot B and Pilot C, as indicated in the right-most column of Table 11, indicate this outcome. The pilots in these two events interpreted and then ignored cues in order to preserve the active frame. Pilot B was not expecting to be heading for a landing using the wrong airfield's approach plates because this rarely occurs in aviation and pilots are not warned or trained to avoid it. Pilot B preserved this frame even when faced with conflicting cues. As an example, he describes his detection of an unexpected VOR: "and I look at my approach plate and the VOR is a different frequency. And that should have been a dead give-away." He recognized a violated expectancy; however, he explained it away: "I justified it…they changed the frequency. The plate is wrong." According to Pilot B, he was also hesitant to dispel this belief because he was very experienced, the flight was routine, and he was flying with a senior instructor.

Pilot C's emergency response training was incongruent with the procedures of the organization overseeing the exercise in which he was participating. This may have caused Pilot C to preserve his own frame and follow the procedures he had been trained to use. Both pilots also related that these events taught them invaluable lessons and techniques that they carried with them through their career.

Contributions to Expertise Literature

The final goal of this research was to compare the sensemaking of military aviation experts to Chi's (2006) compilation of general positive and negative expertise characteristics. An important fact to note is that Chi's compilation is of expert characteristics found in research conducted primarily in controlled laboratory settings. The current research examines experts in their natural domains.

Positive characteristics. According to Chi, experts are able to arrive at effective solutions. The current research suggests that experts may only able to reach effective solutions when the situation is consistent with their experience base. In particular, experts may not even recognize the need to reach a solution if an anomaly they have no reason to expect arises. For example, Pilot B was slow to accept and diagnose his problem when he was trying to land using the wrong approach plate even though there were cues telling him something was wrong. In comparison, Pilot D knew problems might arise when instructing a novice to fly routine maneuvers in difficult environmental factors. This knowledge allowed Pilot D to effectively search and anticipate problems so that an effective solution could be reached.

A second positive characteristic of experts Chi identifies is their ability to detect features such as distinguishing patterns or unique cues. This characteristic is found in Pilot C's immediate use of certain information displays to confirm the engine failure diagnosis, Pilot B's immediate detection of the vertically moving white light, and Pilot D's ability to anticipate possibilities of the student's behavior as he was monitoring through the event.

The third positive characteristic Chi calls out is that experts spend more time analyzing a problem before executing a behavior. This characteristic represents a difference between the studies underlying Chi's compilation and the present naturalistic research. Experts may spend more time analyzing a problem when the stresses of the laboratory are limited. In the current research, the environments were complex, safety critical and time limited. The experts in this research may have spent more time analyzing a problem if they were allotted such time; however, the severity and danger involved in the events caused them to rely on schemas and past knowledge to determine and execute behaviors rapidly versus to spend time analyzing the "problem space".

According to Chi, experts self-monitor more than novices and because they tend to be more aware of their own limitations, experts are better at monitoring how well their abilities match a given situation. This was observed in the present research when Pilot A monitored and adjusted his behavior accordingly due to the high winds. Pilot B and Pilot C both had a more difficult time with self-monitoring, as they believed their behavior was correct. It took more time for them to self-reflect than the others. This may have been due to the details of their events. Finally, Pilot D self-monitored his behavior by adjusting and reacting to the student's behavior in order to teach and keep safety of flight during the event.

Again, the difference in research settings contributes an addition to expert characteristics: experts in this study tended to reflect on situations and their performance after an event had occurred. For example, Pilot B explains more about making the choice to pull out of the situation, "after I pull out, but if I hadn't pulled out, I don't think I would have hit anything but I would have been uncomfortably close. I'm sure of that." In all, the pilots described post-event reflection in all of the six events.

Another characteristic of experts is the ability to implement adaptive strategies when needed. The current research supports this characteristic, as seen in Pilot D's strategy of continuously anticipating possible novice behavior pilot mistakes over the course of a training flight.

In addition, experts are opportunistic in using available resources to handle their situations. The current research also supports this characteristic, as seen in Pilot A's instruction to the sensor operator seated next to him to call out the critical information needed for landing as Pilot A flew his approach. Pilot B also used any resources he had such as the city lights. He was unable to look at his instruments due to the severity of the situation, however the lights provided the confirmation that he was loosing altitude. .

Negative characteristics**.** Although it may seem counterintuitive to examine the negative characteristics of experts, doing so is just as important as examining the positive characteristics because expert weaknesses can reveal the types of aids that can increase experts' abilities.

One of the four negative characteristics described by Chi is the domain specificity of expertise. The current research did not examine this characteristic. There was no evidence obtained to evaluate carry-over of their expertise to other domains.

Experts' overconfidence in their abilities can cause biased reasoning, leading to negative results. The current research provides an example of this characteristic as seen in Pilot B's overconfidence in the accuracy of his approach information and approach performance in the Requalification Flight event. There were many indications that he was not correct; however, the pilot was confident in his landing abilities and initially refused to consider the possibility that he had made a mistake.

The negative characteristic of experts under-estimating novice performance was not seen in the current research, with one possible exception. Pilot D's continuous anticipation of possible trainee errors might be considered a form of underestimating the trainees. In this case, however, underestimating seems an adaptive, positive characteristic.

Finally, inflexibility of experts to changes in rules may not have been seen in the current research. One of the pilots, Pilot C, experienced a change in rule set for responding to inflight emergencies. Whether his resistance to this change is negative or positive is debatable. There were good reasons behind the rule set he knew and he was fully aware of those good reasons; on the other hand, his resistance to the new rule set negatively impacted his situation awareness and thus his performance.

Conclusions

In summary, this cognitive task analysis of expert military aviators in complex environments indicated support for Klein's Data/Frame Model of Sensemaking and provided additional insight into the nature of some of the activities in the model. For example, the dominance of preexisting knowledge used by the experts indicated their extreme reliance on preformed mental models possibly due to the pressure of the environment. The infrequency with which data are actively sought further supports the tendency for experts to rely on their preexisting knowledge in complex, dense environments. Finally, the resistance to reframing when the cues or situation calling for it are not part of the pilots' mental model or experience base, concludes a more organized pattern to sensemaking than Klein states. These findings could aid training and interface design as decision-making is more thoroughly understood.

Results were also consistent with most of Chi's conclusions about characteristics of experts. Exceptions were these experts relied more on their experience base to arrive at solutions, they were not able to analyze their situations due to time limitations, and provided with more time to plan.

This research has the potential to contribute to our understanding of workload capacity, information load capacity, and the process of sensemaking. Greater knowledge in these areas will provide a foundation not just for additional research but also for improved training and sociotechnical system designs.

These findings could also aid the design of how and what information is provided to the pilot, for example what information is critical and what information is not. Understanding the activities and processes involved in decision-making could enhance training regimes and how standard operations should be performed.

In must be noted that a negative aspect in using naturalistic observation is the time it can take to collect data. In the current research, the data was collected over a year. The participants were highly involved within their military domain thus scheduling interviews was difficult. Coding the data was also highly time consuming. In order for both coders to be consistent and in agreement with the coding method, a high percentage of the interviews were discussed and reviewed together. This process served as a training phase for both of the coders. Finally, during this process the definitions of the codes adapted fairly often. Finalized definitions are presented in the research and future research could benefit from using the definitions in order to save time.

Future research could further enhance this current research by using quantitative measures. An example could be to evaluate sensemaking activities during simulated, controlled aviation events. More so, examining behavior during an event where reframing is crucial to safety of flight such as during a catastrophic event. Also, “reaction” questionnaires could be given to pilots after performing an intensive-rich scenario to receive feedback. Once more is known about the handling of information, display placement and designs could be enhanced for improved implementation for pilots and thus increase readiness for their respective tasks.

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Appendices

Appendix A: Participant Background Questionnaire

UAS Crew Pre-Demonstration Background Questionnaire

Date: _____________ Participant #______

All personal information will be kept completely confidential and will not be included in any of the reports or documents being produced as a result of this study.

1. What is your age? ____ years

2. Please indicate your role during this week's flight demonstration:
   ____ Pilot ____ Sensor Operator ____ Mission Commander ____ Other: ________________

3. What military branch(es) are you and have you been affiliated with (reserves or active duty)?
   ___ Army ___ Air Force ___ Marines ___ Navy ___ Coast Guard

4. When did you complete qualification training for CBP UAS operations? ___ yrs ___ mths ago

5. For how long have you been in your current assignment? _____ yrs _____ mths

6. Rate your level of experience communicating directly with ATC in the NAS as a UAS crewmember.
   No experience 1 2 3 4 5 6 7 Very experienced

7. Are you a rated pilot? ○ Yes ○ No

8. If applicable, list types of **manned aircraft**, hours, and highest ratings held for each:

AIRCRAFT	TOTAL FLIGHT HOURS	HIGHEST RATING
________________________	______________________	_____________________
________________________	______________________	_____________________
________________________	______________________	_____________________
________________________	______________________	_____________________
________________________	______________________	_____________________

______________________ ______________________ ______________________

9. If applicable, list past experience in airspace **command and control (C2)** (e.g. AWACS, JSTARS, E2C)?

POSITION/MOS	TOTAL HOURS	ASSIGNMENT DATES (yr -yr)

10. What **UAS** are you currently, have you been, and are you currently certified to operate?

UAS TYPE	POSITION	HIGHEST RATING	CUM. HRS or MTHS

11. Estimate your **total** and **recent flight hours** accumulated as a **UAS Pilot** (or AVO; any platform).

- In protected US airspace: _____ total hrs _____ hrs in past 6 mths

- In Theater of Operations: _____ total hrs _____ hrs in past 6 mths

12. Estimate your **total** and **recent flight hours** accumulated as a UAS **Sensor Operator** (or MPO).

- In protected US airspace: _____ total hrs _____ hrs in past 6 mths

- In Theater of Operations: _____ total hrs _____ hrs in past 6 mths

13. Estimate your **total and recent time** accumulated as a UAS **Mission Commander** (MC).

- In protected US airspace: _____ total mths _____ mths in past 6 mths

- In Theater of Operations: _____ total mths _____ mths in past 6 mths

14. For about how much time have you served as an **'external' pilot,** managing take-offs/launches and landings/recoveries?

____ mths ____ yrs

15. Has any other past experience contributed to your expertise in Customs and Border Patrol UAS operations? If so, please list it below:

____

____

____

____

____

____

Appendix B: Interview Protocol

<u>"How much information can the pilots handle? How much information is too much information?"</u>

Prior to the Interview:

- Ensure participants have read and signed the *Informed Consent Document*.
- Make sure audio recorder is working (test it). Make sure audiotape is labeled correctly. Make sure extra AA batteries are nearby.

The following interview is in support of a thesis for the completion of a masters of science degree from Embry-Riddle Aeronautical University. The interview is designed to find out what information you as an Uninhabited Aerial Vehicle (UAV) pilot **seek, use, ignore** etc. while conducting operations.

I'm going to ask you to walk us through **two events** you've experienced in the past and that are memorable as we're going to ask you to try to recall as many details as possible. As you walk through each event, please try to be **as specific as possible** regarding the event and walk us through, while keeping in mind the goal of information load and management.

All information collected will be protected and kept confidential. Participant numbers will be assigned to your responses. If you would like a copy of your interview transcript, please feel free to contact Katherine Kaste kastek@my.erau.edu or Dr. Kelly Neville nevillek@erau.edu. Thank you for your participation.

The protocol for each of the two events:

First, I'd like you **to recall a situation or even**t that you've experienced and that stands out in your memory. This should be a challenging, difficult, or **unusual event**. It would also be good if it is an **information-intensive** event. I'm after a specific event on a specific day, for example, you land the aircraft at the end of every flight, but I'm after that particular landing on March 5th when something happened that made the landing especially challenging. (Researcher offers suggestion if she or he has one.)

Interviewee chooses an event, relates the idea to the researcher…

After the interviewee chooses an event and the researcher agrees that it is a good choice, give the following instructions:

Please **walk us through** the event starting with what you were doing just before the event began. We'd like to hear how your awareness of the event developed, what you were doing, trying to do, thinking deciding, noticing, communicating, and so forth. Please try to put yourself back into the [pilot's] seat and walk us through the details of that event as best you can.

After the interviewee walks through the event, the researcher tries to recount the details, from the beginning to the end of the event, and asks for clarification and elaboration along the way. In particular, the researcher should seek additional details related to the following prompts:

- How and when the pilot recognized something unusual was happening—what were the cues and did the pilot notice and respond to them all.
- What information did the pilot wish he or she had. What information was he or she anticipating to receive?
- Was any information potentially distracting and was the pilot able to ignore it? What made the information distractible and able to be ignored?
- How did the sensor operator or others help the pilot along the way, or did they?
- What else was the pilot doing or thinking about?
- Had the pilot experienced anything similar previously and, if so, did that past experience influence his response to the current event?

Interview Notes:

We are interested in what information were you attending to. How was the information obtained? What information were you intentionally ignoring? Was there information you were expecting to receive and possibly did not? Rather than answer our questions directly, we would like you to walk us through a specific information-intensive situation or event you encountered while flying.

Appendix C: Coding Definitions – (Adapted from Sieck et al., 2007).

Frame –an organizational structure used to give meaning to data and make sense of the information at hand.

__Codes__

1. Define a frame. Reference goals, constraints, or structural characteristics known about the current situation, i.e., captured in the active frame. (*Not specified by Seick et al. as part of the sensemaking process.)*

2. Seek or choose a frame

2a. Use anchor(s) to elicit frame – Use cues or pieces of data to elicit a frame. (Cues and data used to elicit a frame are considered anchors).

2b. Use experience and context to elicit frame. Use the context of current activities and conditions combined with knowledge of procedures and patterns to elicit a frame that anticipates the next situation or goal. (*Not specified by Seick et al.)*

3. Use data constant in the frame – Use a goal or piece of data that is embedded in the chosen frame to support sensemaking. The data element so reliably co-occurs with the frame that it has become intertwined or pre-packaged with the frame. (*Not specified by Seick et al.)*

4. Confirm and elaborate the frame

4a. Seek data. Take effortful actions to obtain data (versus just use what is given via communications or display); assess understanding of situation to determine whether more data are needed.

4b. Draw inferences and conclusions that extend the frame: Observed data allow the individual to elaborate the frame once more is learned.

4c. Fill data slots in frame. In order to gain a more comprehensive picture of the situation.

4d. Add data slots to frame. In order to gain a more comprehensive picture of the situation.

4e. Combine fragments of frames. When situations have not been encountered previously or vary in fundamental ways each time they're encountered, a single useful frame may not exist and a person may draw from multiple fragments of frames to support sensemaking.

4f. Use pre-existing knowledge to fill data slots: similar to data constant, involves attaching rules to the data within the frame.

For 4a-4c, choose from the following (*Not specified by Seick et al.)**:***

Characteristics of Control Modes: *Derived from E. Hollnagel (2002).*

The Contextual Control Model (COCOM): *"describes how the orderliness of performance depends on the level of control and which provides further details about the selection of actions and the evaluation of events." Describes human performance in terms of feedback and feedforward control cycles and makes explicit the relationship between action and situation understanding, time pressure, and clarity of feedback.*

- **Strategic control:** - The most efficient of the five control modes; Higher-level goals and predictions influence behavior, not just what is in front of the controller. There is abundant time available and the situation can be either routine or novel. The required attention level is medium to high and several goals drive behavior. Evaluation of the outcome is characterized as "elaborate" and involves multiple variables that are both directly and indirectly related.

- **Tactical (attended) control:** Known procedures or rules are followed with care. Adequate time is available and the person perceives the situation as almost routine or routine but important. The work is given a medium to high level of attention. There is constrained set of several goals guiding behavior and evaluation of the outcome is based on the full set of relevant available features so that performance accuracy can be maintained.

- **Tactical (unattended) control:** The work is of the same type as described for tactical attended control but the person is not as conscientious about the accuracy of the control/performance. The time allotted is more than adequate, a low level of attention is given, and a constrained set of several goals guides behavior. Evaluation of outcomes is perfunctory.

- **Opportunistic control:** Features of the current situation and moment drive behavior. This control is used when the data within the environment are incomplete or there is inadequate time to make a decision. The person is familiar but not experienced with the situation and a high level of attention is required. One or two competing goals drive behavior and evaluation of performance outcomes tends to be concrete and limited to obvious changes.

- **Scrambled control:** - Least efficient; Behavior is random trial-and-error. There is very limited time for choosing actions, the person is not familiar with the situation, and full attention is required as the performer tries to find meaning in feedback while experiencing significant time pressure. There is usually one goal being considered and evaluation of outcomes is limited and based on only rudimentary, poorly understood details.

For 4a-4c, also choose from the following (detail codes) (*Not specified by Seick et al.*)***:***

- **Data and inference updates are self-paced:** Checking data value or drawing inference/conclusion is self-paced.

- **Data and inference updates are task-driven:** Checking data value or drawing inference/conclusion is task-driven.

For 4a-4c, also choose the following if applicable *(Not specified by Seick et al.)****:***

- **Use as anchor:** Value, inference, or conclusion is used as an anchor to elicit, establish and confirm frame.

5. Preserve the frame - explain away, minimize the importance of, ignore, or distort data that does not fit the current chosen frame.

6. Question the frame - Question whether or not the incoming data fits the active frame.

6a. Question the quality of the data Seek confirmation of data or the same information from a second or third source.

6ai. One additional sources Obtain confirmatory or back-up information from one source.

6aii. Two additional sources. Obtain confirmatory or back-up information a second source.

6b. Test the frame. Test frame by comparing the results of actions and interactions with frame-based predictions.

6c. Recognize a violated expectancy - Notice that incoming information does not fit predictions derived from the frame, data slots, or expected slot values and, consequently, question the frame's appropriateness.

7. Compare the frame with alternative frames – Identify alternative frames, collect evidence to support the comparison of alternative frames with the active frame, or directly test the most likely frame (e.g., by taking actions and assessing whether the result is what's predicted for a given frame).

8. Reframe – Adapt the active frame or elicit or construct a new frame to support sensemaking in a given situation.

8a. Adapt the active frame. Frame adaptations can involve establishing new anchors, recognizing previously discarded data as relevant, or revising goals.

8b. Elicit or construct a new frame. Eliciting or constructing a new frame supports *sensemaking recovery*, a term Seick et al. use to describe the recognition of a situation for what it really is, versus, for example, what a perceiver expected or wanted it to be.

Appendix D: Example of Coded Data Chunks using the Sensemaking Model

Frame: Maintain a tight orbit within a restricted airspace under high wind conditions that are causing ‘crabbing’ of the aircraft.

Subjective Assessment of Workload: “It was so challenging it was something that you had to constantly focus on. It wasn’t something that you could really take your attention away from for a period of time.”

Pilot A	Author					Human Factors Educator					Final code	Agreement
	High-Level Code	**Specific Code**	**Detail Code**	**Detail Code**	**Focus of Data Chunk**	**High-Level Code**	**Specific Code**	**Detail Code**	**Detail Code**	**Focus of Data Chunk**		**1 - Yes, 2 - No, 3 Reconciled**
Picture it as a box, the airspace we were flying it's a restricted airspace and we were in the southeast corner of that airspace, as far as we could get into the corner.	Define a Frame	Use experi-ence and context to elicit frame			Mission Descript scrip-tion	*Define frame (DF)* *Rows 1-4 also: Seek or choose a frame (SCF*	Use experi-ence or context to adapt or elicit frame	--	--	*Mission descrip-tion*	DF	1
…and we tried to maintain. If we were to fly out of that airspace we would have violated our Certificate of Authoriza-tion (COA).	Define a Frame	Use experi-ence or context to adapt or elicit frame			Mission descrip-tion	DF	--	--	--	*Mission descrip-tion*	*DF*	1

So, trying to give the ground element the best overview and oversight of their target.	Define a Frame				Goal of mission	DF				*Goal*	DF	1
We were in tight...in tight...orbiting turns in that corner.	CEF	FS			Mission descrip-tion	CEF	FS			*Mission descrip-tion*	CEF/FS	1
The winds, if I can remember correctly were around 30 to 40 knots at altitude.	CEF	FS				CEF Rows 5-7 also: SCF	FS Use anchors to adapt or elicit frame				CEF/FS	1
So you would notice your ground speed change…	Confirm and Elabo-rate the Frame	Fill Slot				CEF	FS				CEF/FS	1

…and on your heads down display actual ground speed versus your air speed	CEF	Pre-Existing Knowel dge	DC?			CEF	Draw infer-ences & conclu-sions that extend frame (DIC)				CEF/ Ex-tend	3
You can tell that in your turns, or your downwind leg, that you were crabbing quite a bit to maintain that heading.	Confirm and Elabo-rate the Frame	Draw infer-ences & conclu-sions that extend frame (DIC)	Tactical (attend-ed)	TD		CEF	Extend	Tactical (attend-ed)	TD		CEF/ Ex-tend/T ac (att)/T D	1
…and then the sensor operator that was taking information or requests from the ground element,	CEF	FS				CEF	FS	Strategic	Task-driven (TD)		CEF/F S/Stra t/TD	3

…you know to, uh, maintain eyes on the target at a specific location or grid coordinate so to give him the best view look or angles in my turns around those points,	CEF	Pre-Existing Knowel dge				CEF	Pre-Existing Knowle dge	DC	Stra-tegic	Task-driven (TD)	CEF/Pre/DC /Strategic/TD	3
…determine the type of race track pattern or orbit that we would make so those are the kinds of things we would discuss back and forth between myself…	Confirm and Elabo-rate the Frame	Draw infer-ences & conclu-sions that extend frame (DIC)	Tactical (unat-tended)	Task Driv-en		CEF	Extend the Frame	Strategic	Task-driven (TD)		CEF/ Ex-tend/Strate-gic/TD	3
…and I could hear the ground person speaking as well,	Confirm and Elabo-rate the Frame	Fill Slots	Loose Control	Task Driv-en	**An-chor:** Instruc-tions from SO to Pilot	CEF	FS	LC	TD	*SO's instruc-tions to pilot*	CEF/FS	1

…but then at times the sensor operator would say, "let's make left hand turns versus right hand turn I think that would be a better camera look from this angle…	CEF	FS				Follow Direc-tions					CEF/FS	2
So we may have changed orbit as we were flying. We changed it back from one side to the other.	Elabora-tion					Elabora-tion?					Elabo-ration	1

[…you said you noticed you were crabbing based on your view of the ground speed compared to the airspeed on the head down display, or changes in their relation-ship…and then there was some other piece of information you were using too I think?] Well as you're flying there's a heads down display that will give you your instruments, basically all the…airspeed, your pressures, your sensors in the aircraft.	CEF	FS				CEF	FS	Tactical (unat-tended)	SP		CEF/FS/Tac (un)/SP	3

Then your heads up display is actually roving map or your video display, and it has a little icon of an aircraft on there with a crumb trial.	CEF	FS				CEF	FS				CEF/FS	1
So as you're flying you can, and trying to maintain staying inside that restricted airspace, you can see the aircraft merging closer to the boundary in those wind conditions, which depends on which way you are flying…	Confirm and Elaborate the Frame	Fill Slot	Tactical (attended)	Self-Paced	**Anchor:** Video display of aircraft reaching boundary	CEF	FS	Tactical (attended)	TD		CEF/FS/Tac (att)/TD	3

So you'd have to make a correction further to the right or to the left to maintain that westerly or easterly heading.	Confirm and Elabo-rate the Frame	Draw Infer-ences and conclu-sions that extend the frame	Strategic	Task Driv-en	**An-chor:** Position on map relative to bounda-ry of air space	CEF	Draw Infer-ences and conclu-sions that extend the frame	Tactical (attend-ed)	TD		CEF/ Ex-tend/T ac (att)/T D	1

[So, if you can see the aircraft coming closer to the border up on the heads up…on the map, how do you…how are you also using the speed indicators?] Um it would be…as far as making… in trying to make the turns equal, you know, in distance…so I might go the downwind leg, if I have a tailwind, it might be, for one minute it might take me two minutes to go back westerly direction the other way.	Confirm and Elabo-rate the Frame	Seek Data	Scram-bled	Task Driv-en	Anchor: Aircraft position during each leg	CEF	Draw Infer-ences and conclu-sions that extend the frame	Tactical (attend-ed)	TD		CEF/ Ex-tend/T ac (att)/T D	3

I would maintain a constant spot on the ground, over the ground, without a lot of variation for the operator.	CEF	Pre-Existing Knowel dge				Back-ground				*Goal*	Back-groun d	3
[Is that something you're doing a lot of calculating in your head, to manage?] Yes, not calculator. You might try a minute and a half and if that doesn't work then I'll try two minutes and the next time, whatever gives you the same footprint over the ground.	RI					Redun-dant infor-mation (RI); Same point as two rows up.					RI	1

So you're relying on that map display, to see your relation to where you're at on the map. So that's the difference between manned, unmanned.	Back-ground				Redun-dant Infor-mation	Back-ground					Back-groun d	1

In a manned aircraft you look outside you're either…finger on the map saying, "this is where I'm at," and you can see your drift. Well in an unmanned aircraft you're really not using that look down…the cameras looking at the target and you're forward looking camera only has a field of view off the nose of the aircraft, so you don't have a relation to the ground from that, uh, that "day TV" camera that is within a certain degree…field of view off the nose…	Back-ground					Back-ground					Back-groun d	1

So you're using the heads up map display and watching your icon track…	RI					RI					RI	1
…across the map and it gives you that drift relation, or that, uh, crabbing angle as well.	CEF	FS				RI					RI	3

[So, if you're in a manned aircraft, um, and so…I'm so…it's interesting to hear that, how much in the manned aircraft you are actually looking out [right, right] what happens then, would you just not be doing this type of a task if it was, um, bad really poor weather? Or…] No, well, weather minimums are no different from manned to unmanned or they might be more restrictive depending on the type of aircraft you're flying, but that would make a difference. If I understand your question correctly…	Back-ground					Back-ground					Back-groun d	1

[But this gets harder for you in the unmanned probably compared to the manned it gets relatively harder as the winds pick up and that sort of thing it sounds like, um, you said it was 30 to 40 knots in this particular situation which made it really challenging.] It was so challenging, it was something that you had to constantly focus on. It wasn't something that you could really take your attention away from for a period of time.	Work-load					Work-load					Work-load	1

…because the proximity we were to the boundary line, you know we were within, probably 50, or probably 100 meters of being outside of our spot,	Define Frame					DF					DF	1
…which was probably closer then we should've been…it wasn't that big of a deal just that it was something we had to pay real close attention to…because we didn't want to violate our authorization that we had with the FAA at that time	CEF	Pre-Existing Knowledge	DC			CEF	Pre-Existing Knowledge	DC			CEF/Pre/DC	1

[you were making a decision about um, there was a decision I guess whether to go right or left or the what the path or track should be, um, are you involved in that decision as the pilot? Or are you letting the others…] Oh yes…yes, it's, uh, aviate first so if they want you to do something you gatta accommodate as you can…you know, you might take an extra turn, or say, "I'll be with you in a minute,"	Back-ground					CEF	Pre-Existing Knowledge	Meta-Knowledge			CEF/Pre/Meta	3

I have to, whatever I need to do to put the aircraft where I want it to be…per my flight plan or per what I am authorized to do…and then as I can accommo-date them…they take second place if you know what I mean.	Back-ground					RI					RI	3

[And, uh, can you remember from that particular incident, how you, what information you, or what feedback you were giving to the sensor operator, or as best you can maybe…and to the ground element] It was basically saying that, uh, depending on the turns that I was taking and how that was affecting…um is looked down with the camera because if the wing, your wing is over sometimes that would…if it's a tight turn that would obstruct your view with the target momentarily if that was going to be an issue or not, and uh…um…so it was…	Confirm and Elabo-rate the Frame	Fill Slot				CEF	Pre-Existing Knowle dge	DC		*observe wing angle and visibility of target*	CEF/P re/DC	3

[So you let them…]It wasn't that it…it was just whatever was given the best look angle so if I had a shallow turn it turns out then well I had to make sure there was enough distance so that I wouldn't encroach on the boundary line…so I might have made a shallower turn at that one corner of the airspace versus the other side I would have made a standard return.	CEF	Draw infer-ences and conclu-sions that extend the frame	Strategic	Task Driv-en	**An-chor:** angle of turn based on bounda-ry	CEF	Draw infer-ences and conclu-sions that extend the frame	Strategic	TD	*deter-mine appro-priate wing angle based on distance from bounda-ry*	CEF/ Ex-tend/S trate-gic/T D	1

[And does the sensor operator and the ground element, are they...do they understand those decisions that you have to make or are you talking them through it as you do this?] No, no that's understood because its not assumed, but it's after working with them so long they understand that…they wait for the turn…or if the camera operator cannot maintain track for a few seconds, then they just wait until it's back on.	Background				CRM description	CEF	Pre-Existing Knowledge	Meta-Knowledge			CEF/Pre/Meta	3