Anticipatory Thinking

Gary Klein
Applied Research Associates, Inc.
gary@decisionmaking.com

David Snowden
Cognitive Edge Pte Ltd
snowded@mac.com

Chew Lock Pin
Defence Science and Technology Agency
clockpin@dsta.gov.sg

ABSTRACT

Anticipatory thinking is a critical macrocognitive function of individuals and teams. It is the ability to prepare in time for problems and opportunities. We distinguish it from prediction because anticipatory thinking is functional—people are preparing themselves for future events, not simply predicting what might happen. And it is aimed at potential events including low-probability high threat events, not simply the most predictable events. Anticipatory thinking includes active attention management—focusing attention on likely sources of critical information.

We distinguish three types of anticipatory thinking: pattern matching to react to individual cues, trajectory tracking to react to trends, and a conditional form of anticipatory thinking in which people react to the implications of combinations of events. We discuss some individual and team-level barriers and suggest some ways to enhance anticipatory thinking.

Keywords

Anticipation, expectancy, prediction, problem detection

WHAT IS ANTICIPATORY THINKING?

Anticipatory thinking is the process of recognizing and preparing for difficult challenges, many of which may not be clearly understood until they are encountered. It is a form of sensemaking. Sensemaking often takes the form of explaining events and diagnosing problems, a retrospective process (e.g., Weick, 1995). It can also take the form of formulating expectancies about future events (e.g., Weick & Sutcliffe, 2001). It is this future-oriented aspect of sensemaking that interests us here—anticipatory thinking.

The ability to perform anticipatory thinking is a mark of expertise in most domains. For example, deGroot (1946/1978) provided protocols of grandmasters studying chess positions and trying to find the move to play. Many of their comments show instant reactions upon considering a possible move, such as recognition that a move is promising, or else "Take it away," to reflect immediate disapproval. The grandmasters didn't have to perform progressive deepening to appreciate where they might be able to take control and where they would be getting themselves into trouble.

We distinguish anticipatory thinking from prediction. Certainly, anticipatory thinking overlaps with prediction and relates to the Level 3 situation awareness described by Endsley (1995) as well as the Hawkins and Blakeslee (2005) formulation of the brain as a device for storing memories in order to make predictions. However, we believe it is a mistake to see anticipatory thinking as a means of predicting what will happen. Instead, we are gambling with our attention to monitor certain kinds of events and ignore/downplay others. We are building directly through experience, and indirectly through stories, patterns of meaning and response which can be used or blended to deal with an as yet unknown, and unknowable future. The ability to blend different concepts, experiences and stories is a key part of human intelligence and permits us to handle higher levels of uncertainty and ambiguity.

For example, experienced drivers are actively scanning for potential hazards, unlike novices. Pradhan et al. (2005) studied the eye movements of skilled and inexperienced drivers and found that the skilled drivers directed their focus to potential trouble spots. In contrast, the inexperienced drivers ignored these trouble spots, presumably keeping their eyes on the road to make sure they kept their car within the lanes. The experienced drivers aren't expecting the hazards or predicting them but they are managing their attention appropriately. Experience and training have created the right patterns. Therefore, they have

heightened sensitivity to weak signals that would be ignored by those with less experience. They have an edge in detecting problems.

Another difference is that anticipatory thinking is aimed at potential events including low-probability high threat events, not simply the most predictable events.

There is a more fundamental difference between prediction and anticipatory thinking. The process of prediction is externally directed and usually concerned with guessing future states of the world. In contrast, anticipatory thinking also includes preparing to respond. Klein, Phillips, Rall, and Peluso (2007) studied information operations specialists and found that the more experienced ones engaged in "functional sensemaking." They weren't simply noting the content of messages but were interpreting the messages in terms of what information operations they could initiate. Their sensemaking centered on what they could do. Therefore, we take a functional view of anticipatory thinking. We are sensitive to the affordances in the situation, and affordances are a function of our beliefs about our own capabilities. When we anticipate events we are also preparing ourselves to react.

Think about a sports event. Sometimes, when we don't care, we might predict that that favored team will win the game. But when we do care, and our team is the underdog, we say we are anticipating a loss—we are preparing ourselves for the disappointment.

In his book "Fundamental Surprise," Lanir (1986) showed that in military examples of surprise the signals were fairly strong. The reason for the surprise was that the military officers overestimated their own abilities to react. Thus, we fail to anticipate when we don't prepare ourselves, either because we don't notice the signals or because we don't worry about them and don't bother to prepare ourselves. Anticipatory thinking depends on our capability to prepare, and not just our ability to predict future states of the world. Indeed over preparation around a "predicted" set of scenarios may reduce our capacity to exercise our ability for anticipation and adaptation, or blending of patterns.

VARIETIES OF ANTICIPATORY THINKING

In reviewing various examples of anticipatory thinking we found several different forms, and we expect that researchers will identify additional forms in the future. Three common forms are pattern matching, trajectory tracking, and conditional.

Pattern Matching

With pattern matching the circumstances of the present situation bring out similar events and clusters of cues in the past. Experts have developed large pattern repertoires and so can immediately be on guard if they notice something untoward. Anticipatory thinking doesn't only involve problem detection but one of its greatest values is to provide an early warning system when we are about to run into trouble. For example, a physician1 related a story of how, as a third year medicat student, he puzzled over the diagnosis for a recently admitted patient complaining of shortness of breath. He ran a variety of tests, pondered their results, and formulated hypotheses. Then the senior physician came to the room – and just as he walked through the door, even before reaching the patient's bed, exclaimed "Oh, a case of heart failure!" And, of course, this was the correct diagnosis. Greater experience and higher levels of expertise make it more likely that our anticipatory thinking will be accurate and successful. (We discuss anticipatory thinking in the context of recognitional decision making in a later section). They also carry a danger, namely overconfidence in our experience may lead us to make a diagnosis, but miss something new or novel that may be seen by the naïve observer.

Trajectory Tracking

Sometimes anticipatory thinking requires people to get "ahead of the curve." The curve is the trajectory of events, and getting ahead of the curve means preparing yourself for how the events are unfolding and how long it will take you to react. It means noticing and extrapolating trends. But it also requires a functional perspective. Infants have trouble catching a ball that you roll past them because they initiate their reaching response aimed at where the ball is. With age and practice they learn to reach where the ball will be by the time they can move their hand. Beach and Mitchell (1990) have highlighted trajectory tracking as the basis of his account of decision making. And, again, anticipatory thinking here blends the external events and the internal preparations and capabilities.

[1] I am indebted to Peter Bach for this example.

Trajectories can be seen as types of cues. We make the distinction because of the additional complexity needed to track trajectories and compare what is expected with what is observed. The mechanisms for these kinds of trajectory tracking and comparisons may differ from the mechanisms of directly associating a cue with a threatening outcome.

This is one of the areas where we use narrative. By paying attention to the experiences of others, generally expressed through stories we build additional patterns that we can use to govern our response to future events. Narrative is a fundamental mechanism for meaning making (Kurtz & Snowden, 2003) and is of particular use in trajectory tracking and critically in understanding the possible trajectories of other actors in the decision space.

Conditional

This type of anticipatory thinking requires us to see the connections between events. Instead of responding to a cue, as in pattern matching or to a trajectory, we also need to appreciate the implications of different events and their interdependencies.

Here is a personal example of a failure of anticipatory thinking. One of us (GK) took a flight from Dayton, Ohio to New York City and left his car in the airport parking lot. He tucked his car keys in his briefcase because he wouldn't need them while in New York. For complex reasons he was unable to fly home but instead took a train from New York to Toledo, Ohio where he was picked up by a relative and driven south to Dayton. He was dropped off at the Dayton airport so he could reclaim his car. As he left the relative's car he wondered if he should take his suitcase and briefcase with him but didn't see any reason to do so – he and the relative were both going to drive to his home and he could get the suitcase and briefcase at that time. As he approached his car he realized his mistake. If GK had been questioned a minute earlier he would have been able to correctly answer all these questions: Where is your car? (In the airport parking lot.) Where are your car keys? (In my briefcase.) Where is your briefcase? (In my relative's car.) Where is your relative's car? (Currently driving away from the airport.) The problem is that all four facts stayed separate until too late. This example shows a failure of conditional thinking. It was a failure to anticipate that he would need the briefcase and car keys as he got out of the relative's car.

Conditional thinking may require mindfulness, more mindfulness than GK showed. Langer (1989) and Weick, Sutcliffe, and Obstfeld (1999) have discussed the importance of mindfulness for skilled performance and safety however it is not clear as to the degree to which context is critical to different types of mindfulness. Hnwever, many times the conditional relationships forge their own connection without being willed. Whether deliberate or unconscious, we need to notice inconsistencies (e.g., where are the car keys and how can I drive without them) in time to prevent problems.

In addition to catching inconsistencies, the conditional form of anticipatory thinking is how we notice connections—events whose significance is conditioned by each other. In one high-level Marine Corps exercise (Klein *et al.,* 2000) the planners had not done a very thorough job and the exercise controllers decided to teach them a lesson. The plan left a very weak defense against an attack from the north so the controllers got ready to launch precisely this type of attack. They were gleefully awaiting the panicked response of the Marine unit they were going to punish. However, the Marines had augmented their staff with some experienced Colonels who had formerly been on active duty but now in the reserves. These Colonels had no real responsibilities. They didn't report to anyone or have anyone report to them. So they could just wander around. One of them noted a situation report that an enemy mechanized brigade had just moved its position. That was odd – this unit only moved at night, and it was daytime. He wondered if it might be on an accelerated time schedule and was getting ready to attack. (The technician who noted this movement had no idea of its implications.) Checking further, the Colonel talked to the Senior Intelligence Watch Officer who was also suspicious, not because of any event but because of a non-event. The rate of enemy messages had suddenly declined. This looked like the enemy was maintaining radio silence. Based on these kinds of fragments, the Colonel sounded an alert and the unit rapidly generated a plan to counter the attack—just in time.

ASPECTS OF ANTICIPATORY THINKING

Anticipatory thinking is linked to most if not all of the macrocognitive functions and processes described by Klein. Ross, Moon, Klein, Hoffman, and Hollnagel (2003). It is part of decision making, particularly the generation of expectancies within accounts such as recognition-primed decisions (Klein, 1998). As discussed earlier, anticipatory thinking is one type of sensemaking; explanation/diagnosis is the other type. It is essential to planning and replanning, for preparing to alter trajectories and for taking a functional view. It is critical to coordination—effective teams need to have interpredictability so that team members successfully predict each other's reactions and successfully anticipate how they will each react to unexpected events. At the level of team interactions team sensemaking depends on the coordination of anticipations.

Anticipatory thinking is a form of problem detection. Klein et al. (2005) showed that problem detection is not simply accumulating discrepancies until some threshold is reached—in many cases it requires a re-framing of situational understanding in order to appreciate the significance of the evidence. That means shifting mental models and frames.

Anticipatory thinking is expressed through attention management as illustrated by the research on the eye movements of drivers. It forms the basis of common ground because without anticipatory thinking we couldn't maintain dialogs and we couldn't be surprised by the reactions of others—indicators that common ground has broken down and has to be repaired.

Anticipatory thinking is also a form of mental simulation and the generation of expectancies. Warwick and Hutton (2007), in trying to develop a computational version of the Recognition-Primed Decision Model, found that expectancies turned out to be a key component. In order to make progress they had to move beyond the notion of expectancies as triggers for process-level effects to a level reflecting the decision maker's causal understanding of a situation. They also had to move beyond a knowledge-level explanation of expectancies to a more functional account that linked the decision maker to the environment.

BARRIERS TO ANTICIPATORY THINKING

Unhappily, the set of barriers that interfere with anticipatory thinking is fairly long. For starters, they include: taking a passive as opposed to mindful stance; fixation/pattern entrainment (DeKeyser & Woods, 1993); knowledge shields that we use to explain away inconsistencies (Feltovich *et al.*, 1994); and overconfidence in one's own capabilities. On top of these we also have to contend with team and organization-level barriers: organizational policies that filter weak signals; perverse incentives; disconnects between the data collector and the data integrator; difficulties in directing someone else's attention. Klein (2006) has described a variety of barriers to problem detection at the team/organizational level.

We recently completed a pilot study to see if we could improve anticipatory thinking in small teams (Snowden, Klein, Chew & Teh, 2007). Specifically, we wanted to overcome failures in anticipatory thinking resulting from attention entrainment/fixation/garden path thinking, dismissal of alarms raised by people noticing weak signals; confusions about mission intent. We primarily wanted to increase the likelihood of noticing and reacting to weak signals.

The study used military and intelligence scenarios presented to seven small teams (n=4-5 per team) of professionals working in related organizations in Singapore. Each scenario included weak signals – to determine if and when the team noticed these signals and their implications. At predetermined break points each team member wrote individual notes about what was happening. We also observed the team discussions.

We examined a few techniques to improve performance such as having the team members examine attractors and barriers to their mission, a crystal ball method for considering alternative explanations for events, a ritualized dissent technique, and a prospective hindsight method. Data were collected using narrative capture as well as a method for calibrating situation awareness.

A key finding is that at least one individual in every group did notice the weak signals and their implications and typically half the group noticed the weak signals, based on the individual notes. However, no team took these early signs seriously. Usually, they weren't mentioned at all. If mentioned, they were dismissed. So the groups themselves did not "consciously" pick up or act on those signals. Therefore, the challenge shifts from helping people recognize weak signals to helping their groups and organizations take advantage of the anticipatory thinking of individuals.

Useless advice regarding anticipatory thinking

- Gather more data.
- Use information technology to help analyze the data.
- Reduce judgment biases.
- Encourage people to keep an open mind.
- Appoint "devil's advocates" to challenge thinking.
- Encourage vigilance.

We are not enthusiastic about any of these recommendations.

Why gather more data? The historical record of so-called surprises shows that in just about every case the data were available to anticipate the surprise. The decision makers explained away the data. Therefore, adding more relevant data (along with lots of non-relevant data that will muddy the picture) will not necessarily improve anticipatory thinking. Prior to Operation Barbarossa (Hitler's "surprise attack" on the Soviet Union during WWII), Stalin received more than 50 different warnings. For Pearl Harbor, the indicators of a surprise Japanese attack are clear once we strip away the additional data, and once we put these data together (which the different bureaucracies were unable to do). Lanir and others have described all the indicators of the Yom Kippur War and how the Israeli Defense Forces dismissed these because of an exaggerated confidence in their own defenses. And the 9/11 industry is still uncovering message trails that should have alerted the U.S. to the impending attack.

Because of these kinds of incidents, Heuer (1999) has argued that the intelligence agencies need better analysis, not more data. Further, Stewart, Roebber, and Bosart (1997), Omodei, Wearing, McLennan, Elliott, and Clancy (2004) and others have empirically shown that having more data doesn't improve accuracy. The increased data may increase confidence, thereby exacerbating problems with overconfidence.

Can we rely on information technology to help us analyze data and improve anticipatory thinking? Klein (2004) has described the various ways that automation can make people stupid. For example, fusion algorithms reduce uncertainty by helping us cope with data overload. But typically the people using these algorithms don't understand the programming and don't know the skill level of the people who created the algorithms, so the uncertainty has just been shifted to another level. Mosier (1997) and Smith et al. (1997) have argued that automated support systems create passivity, not increased vigilance.

For many years the notion of "de-biasing" decision makers has been advocated to counter the laboratory findings of systematic judgment biases. However, the laboratory studies have been misinterpreted. They really demonstrated the use of heuristics by showing that people used heuristics even when the heuristics resulted in sub-optimal performance. There is much more debate about whether our heuristics/biases are a source of problems outside the laboratory (L. J. Cohen, 1981; M. S. Cohen., 1993). Further, the standard methods for reducing biases are to ask people to list all assumptions, identify the uncertainties, etc. The focus is on avoiding mistakes, not on activating suspicions. There is no evidence that these methods actually work.

Another piece of advice is to keep an open mind. However, Dowie and Elstein (1988) showed that physicians were unable to keep an open mind in preparing diagnoses. Rudolph (2003) suggests that keeping an open mind may be a bad idea, even if it was possible. She performed a study of anesthesiologists working on a Garden Path scenario. She found that the anesthesiologists who fixated on the initial (misleading) cues showed the worst performance, but those who kept an open mind were not much more successful. The most effective strategy was to formulate early hypotheses and to test these. This is an active strategy (as opposed to the passivity of keeping an open mind).

What about using Devil's Advocates to aid groups with anticipatory thinking? Nemeth, Rogers, and Brown (Nemeth *et al.*, 2001) found just the reverse. Having a Devil's Advocate increased support for the orthodox opinions in the group—perhaps because the group felt that the Devil's Advocate had created a balanced view and so the individuals didn't personally need to engage with the contrary data. Further, the use of Devil's Advocates added little to the quality of the group solutions. The comments of Devil's Advocates are disregarded because they aren't open to debate and discussion. The Devil's Advocates are simply playing a rigid role as contrarians. Authentic dissenters do improve group performance, but at a cost—the authentic dissenters are often marginalized in a group. This fear of marginalization may have inhibited many of the participants in the Klein et al. pilot study from voicing the concerns that they recorded privately.

Finally, what about the advice to encourage vigilance? Unfortunately, people cannot will themselves to be smarter. Vigilance isn't a substitute for expertise. Baxter et al. (2004) presented young Marine Corps officers with a counter-reconnaissance task. Their job was to set up an ambush for the adversary's reconnaissance teams. At each phase of the mission the scenario generated some surprise that caused the ambush to fall apart. The Marine officers were expecting to be surprised. They knew something unexpected was coming. And yet they never were able to anticipate what it was. The experiment even provided them with cues. Neighboring units were hit with the same surprise just a few minutes earlier, or a confederate asked them a leading question. All to no avail. Without the experience base to appreciate what these cues meant the officers were unable to anticipate what was about to happen to them.

IMPROVING ANTICIPATORY THINKING

We structure this section by considering the ways that anticipatory thinking may break down and some kinds of interventions to reduce or avoid the breakdown. Some of the common breakdowns result from fixation, weak mental models, organizational barriers, automation, and perspective.

The fixation problem has been amply demonstrated and discussed (e.g. DeKeyser & Woods, 1993; Feltovich et al., 1994; Lovallo & Kahneman, 2003; Rudolph, 2003) have suggested the value of an "outside view," using analogs to provide a reality check. Another approach is to bring in fresh eyes that have not yet been captured by the dominant interpretation of the situation. In contrast to a devil's advocate, these fresh eyes bring with them authentic dissent.

Weak mental models serve as a limiting factor for effective anticipatory thinking. One approach is to value and develop expertise. Klein (Klein, 2004; Klein & Baxter, 2006) has described a range of techniques for speeding up the growth of expertise. Snowden (2000) has taken a different tack, exploring techniques for re-conceptualization using high abstraction

languages or metaphor. For example, the attractors/barriers exercise seeks to strengthen anticipatory thinking by having people alter their perspectives of a situation. Organizations may try to slow down the rapid rotation assignments so that people can gain more experience. And that raises the question of how organizations support or impede anticipatory thinking.

Organizational barriers can take two forms. *Between-organization* barriers impede the flow of ideas, interpretations and information; *within-organization* barriers discourage people from voicing unpopular concerns. One approach for reducing between-organization barriers is to set up liaison officers or units. However, this stop-gap method doesn't overcome the problem that people's primary allegiance is with their home organization, so that organizational rivalries still operate. Perhaps a more intense solution is to truly establish new units drawing from the rival groups (in order to use their networks and expertise) but with a unified hierarchical structure. Turning to within-organization barriers, methods such as the use of Devil's Advocates don't seem to work. Snowden et al. (2007) have explored different approaches to ritualized dissent in which the team members are expected to voice unpopular but sincere beliefs. The PreMortem method (Klein, 1998) and Snowden's "hot seat" method are two examples that have gathered at least anecdotal support. Another approach has been described by Weick, Sutcliffe and Obstfeld (1999) who studied High Reliability Organizations and found that they took a mindful and active stance towards potential problems, compared to the mindless and dismissive attitude of companies and industries that tolerated higher accident rates.

Complexity. Obviously, high degrees of complexity pose challenges to anticipatory thinking. Military organizations try to overcome complexity by structing situations – setting up boundaries, reducing the adversary's degrees of freedom, in order to permit trajectory tracking and conditional implications.

Automation can increase passivity, thereby interfering with the active mindset needed for anticipatory thinking. Cognitive Systems Engineering methods (e.g., Hollnagel & Woods, 1983; e.g., Rasmussen *et al.*, 1994) have been developed to improve the design of information technologies so that they support anticipatory thinking. These methods are intended to ward off "technophiliacs" and to maintain focus on strengthening and supporting the cognitive functions of the decision makers.

Team coordination. Anticipatory thinking is essential to teams as well as for individuals. Klein et al. (2004) have discussed the importance of interpredictability for teams, and Serfaty et al. (1998) have described an anticipation ratio measuring a team's implicit coordination in terms of the tendency to send messages before those messages were requested. To improve anticipatory thinking for teams we can use a "see-attend-act" distinction. Someone on the team has to do the anticipatory thinking to become alert to a possible threat. The commander and other team members have to attend to the cues and the potential threat. And they have to prepare themselves to react.

CONCLUSIONS

Anticipatory thinking isn't just another new term. It is a form of sensemaking, looking forward rather than retrospectively. It is different than prediction. While it intersects with virtually all of the macrocognitive functions (e.g., decision making, planning and coordination), it is different from each of these functions. It may operate in different ways than the explanatory forms of sensemaking. We believe that anticipatory thinking is critical to effective performance for individuals and for teams. This paper offers some initial thoughts about the nature of anticipatory thinking, and we hope these will stimulate additional investigation.

REFERENCES

Baxter, H.C., Harris, D., & Phillips, J.K. (2004). Evaluating a scenario-based training approach for enhancing situation awareness skills. Paper presented at the Interservice/Industry Training, Simulation and Education Conference, Orlando, FL.

Beach, L. R., & Mitchell, T. R. (1990). Image theory: A behavioral theory of decisions in organizations. In B. M. Staw & L. L. Cummings (Eds.), *Research in organizational behavior* (Vol. 12). Greenwich, CT: JAI Press.

Cohen, L. J. (1981). Can human irrationality be experimentally demonstrated? *The Journal of Behavioral and Brain Sciences, 4*(3).

Cohen, M. S. (1993). The naturalistic basis of decision bias. In G.A. Klein, J. Orasanu, R. Calderwood and C.E. Zsambok (Eds.) Decision making in action: Models and methods. Ablex: Norwood, NJ.

de Groot, A. D. (1946/1978). *Thought and choice in chess*. New York, NY: Mouton.

DeKeyser, V., & Woods, D. D. (1993). Fixation errors: Failures to revise situation assessment in dynamic and risky systems. In A. G. Colombo & A. Saiz de Bustamente (Eds.), *Advanced systems in reliability modeling*. Norwell, MA: Kluwer Academic.

Dowie, J., & Elstein, A. (1988). *Professional judgment: A reader in clinical decision making*. Cambridge: Cambridge University Press.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*(1), 32-64.

Feltovich, P. J., Coulson, R. L., Spiro, R. J., & Adami, J. F. (1994). *Conceptual understanding and stability, and knowledge shields for fending off conceptual change*. Final Report, Contract N00014-88-K-0077, Cognitive Science Division, Office of Naval Research. Also CKRP Technical Report #7, School of Medicine, Southern Illinois University, Springfield, Ill.

Hawkins, J., & Blakeslee, S. (2005). *On intelligence*. New York: Times Books, Henry Holt and Co.

Heuer, R. J., Jr. (1999). *Psychology of intelligence analysis*. Washington, D.C.: Center for the Study of Intelligence, Central Intelligence Agency.

Hollnagel, E., & Woods, D. D. (1983). Cognitive systems engineering: New wine in new bottles. *International Journal of Man-Machine Studies, 18*, 583-600..

Klein, G. (1998). *Sources of power: How people make decisions*. Cambridge, MA: MIT Press.

Klein, G. (2004). *The power of intuition*. New York: A Currency Book/Doubleday.

Klein, G., & Baxter, H. C. (2006). *Cognitive transformation theory: Contrasting cognitive and behavioral learning.* Proceedings of the Interservice/Industry Training, Simulation & Education Conference (I/ITSEC), Orlando, FL.

Klein, G., Feltovich, P. J., Bradshaw, J. M., & Woods, D. D. (2004). Common ground and coordination in joint activity. In W. B. Rouse & K. R. Boff (Eds.), *Organizational Simulation*. New York: John Wiley & Sons Inc.

Klein, G., McCloskey, M. J., Phillips, J., & Schmitt, J. (2000). Decision making in the marine expeditionary force (MEF) combat operations center. *Proceedings of the 2000 Command and Control Research and Technology Symposium (CD-ROM)*.

Klein, G., Phillips, J. K., Rall, E., & Peluso, D. A. (2007). A data/frame theory of sensemaking. In R. R. Hoffman (Ed.), *Expertise out of context: Proceedings of the 6th international conference on naturalistic decision making*. Mahwah, NJ: Lawrence Erlbaum & Associates.

Klein, G., Pliske, R. M., Crandall, B., & Woods, D. (2005). Problem detection. *Cognition, Technology, and Work, 7*, 14-28.

Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., & Hollnagel, E. (2003). Macrocognition. *IEEE Intelligent Systems, 18*(3), 81-85.

Kuirtz, C.F. & Snowden, D.J. (2003). The new dynamics of strategy: Sensemaking in a complex and complicated world. e-Business Management, 42.

Langer, E. J. (1989). *Mindfulness*. Reading, Mass.: Addison-Wesley Publications Co.

Lanir, Z. (1986). *Fundamental surprise*. Eugene, OR: Decision Research.

Lovallo, D., & Kahneman, D. (2003). Delusions of success. *Harvard Business Review, 81*(7), 57-63.

Mosier, K. L. (1997). Myths of expert decision making and automated decision aids. In C. E. Zsambok & G. Klein (Eds.), *Naturalistic decision making* (pp. 319-330). Mahwah, NJ: Lawrence Erlbaum & Associates.

Nemeth, C., Rogers, J., & Brown, K. (2001). Devil's advocate vs. authentic dissent: Stimulating quantity and quality. *European Journal of Social Psychology, 31*, 707-720.

Omodei, M. M., Wearing, A. J., McLennan, J., Elliott, G. C., & Clancy, J. M. (2004). More is better? Problems of self-regulation in naturalistic decision making settings. In B. Brehmer, R. Lipshitz & H. Montgomery (Eds.), *How professionals make decisions*. Mahwah, NJ: Lawrence Erlbaum & Associates.

Pradhan, A.K., Hammel, K.R., DeRamus, R., Pollatsek, A., Noyce, D.A. & Fisher, D.L. (2005). Using eye movements to evaluate effects of driver age on risk perception in a driving simulator. *Human Factors, 47*, 840-852.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive systems engineering*. New York: John Wiley.

Rudolph, J. W. (2003). *Into the big muddy and out again.* Unpublished Doctoral Thesis, Boston College, Boston, MA.

Serfaty, D., Entin, E.E., & Johnston, J. (1998). Team adaptation and coordination training. In J.A. Cannon-Bowers & E. Salas (Eds.) *Decision making under stress: Implications for training and simulations.* Washington D.C.: APA Press.

Smith, P.J., McCoy, E., & Layton, C. (1997) Brittleness in the design of cooperative problem-solving systems: The effects on user performance. *IEEE Transactions on Systems, Man and Cybernetics, 27*, 360-371.

Snowden, D. J. (2000). The art and science of story or 'are you sitting uncomfortably? Part 1: Gathering and harvesting the raw material'. *Business Information Review, 17*(3), 147-156.

Snowden, D.J., Klein, G., Chew, L.P. & Teh, C.A. (2007). A sensemaking experiment: Techniques to achieve cognitive precision. Proceedings of the 12th International Command and Control Research & Technology Symposium..

Stewart, T. R., Roebber, P. J., & Bosart, L. F. (1997). The importance of the task in analyzing expert judgment. *Organizational Behavior and Human Decision Processes, 69*, 205-219.

Warwick, W., & Hutton, R. J. B. (2007). Understanding models of the recognition primed decision from both a computational and theoretical perspective. In R. R. Hoffman (Ed.), *Expertise out of context: Proceedings of the sixth international conference on naturalistic decision making*. Mahwah, NJ: Lawrence Erlbaum & Associates.

Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks, CA: Sage Publications.

Weick, K.E. & Sutcliffe, K.M. (2001). *Managing the unexpected: Assuring high performance in an age of complexity*. San Francisco: Jossey-Bass.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (1999). Organizing for high reliability: Processes of collective mindfulness. *Research in Organizational Behavior, 21*, 13-81.