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Cognitive Offloading Strategies and Decrements in Learning: Lessons from Aviation and Aerospace Crises

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ABSTRACT

Examples from aviation and aerospace illustrate the potential consequences that emerge when organizations replace learning from experience with technology, a process referred to as a cognitive offloading strategy (COS). Examples include the Air France Flight 447 crash involving an Airbus 330-203 and the Lion Air Flight 610 crash involving a Boeing 737 Max. From the perspective of human performance in extreme environments, COS represents an underexplored source of organizational vulnerability which presents a particular challenge for learning in organizations. Decrements in learning result from COS because COS creates gaps in procedural knowledge and deprives operators of opportunities to learn in the face of event-induced stress. Due to the inevitability of COS in extreme environments, recommendations for building resilience include offering training scenarios that support the development of a positive stress response, facilitating the ability to learn in the face of uncertainty, and supporting highly engaged experiential learning to build procedural (and often tacit) knowledge of operations.

Keywords: individual learning, organizational learning, procedural knowledge, cognitive offloading, training, extreme environments, crisis, disaster

Introduction

The paper introduces the notion of cognitive offloading strategy (COS) to describe the process of introducing new technologies that serve as a substitute for human learning. By exploring COS, the paper identifies potential organizational vulnerabilities that lie at the intersection of learning, stress, and the introduction of new technology. Often, when organizations prioritize efficiency, they rely on COS to override costly and time-consuming training. The risk is that COS leads to decrements in learning resulting from gaps in procedural knowledge and limited opportunities to learn in the face of event-induced stress.

Aviation and aerospace disasters, including the Air France Flight 447 crash involving an Airbus 330 and the Lion Air Flight 610 crash involving a Boeing 737 Max, illustrate these potential vulnerabilities. Examples from Apollo 11 and the space station Mir illustrate how to build resilience considering the inevitable use of COS in organizations. The paper argues that extreme environments such as aerospace and aviation represent an important context to explore learning in organizations and connect that learning to research on organizational disaster, crisis, and breakdown. The paper concludes with recommendations on how organizations can moderate the negative impact of COS on learning, which include understanding the nature of tasks that COS may leave vulnerable, building procedural knowledge that leads to a tacit understanding of underlying technology through experiential learning, training in a team or social context, and creating engaging opportunities to learn under stress.

Cognitive Offloading Strategies

COS describes any process by which people shift cognitive tasks to external sources (Dunn & Risko, 2015; Risko & Gilbert, 2016). COS can be simple, such as writing in journals, using manuals, or relying on calculators. It can also be more complex and is a key ingredient in driver-assist features of cars, such as rear bumper warnings, and a common feature of modern computer-based fly-by-wire aircraft.

For individual cognition and learning, the reasons for and benefits of offloading are varied, but there is some agreement that at the individual level, COS makes things easier. Offloading is more than just a lazy act; it serves an evolutionary benefit. Cognitive psychologists believe that the brain seeks to limit the amount of work it performs to free up brain capacity

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for more complex tasks, a phenomenon called the free energy hypothesis. This hypothesis is based on the notion that the brain has limited capacity and can only process a limited number of tasks before exhaustion. To preserve energy for the most important tasks, the brain does everything it can to optimize "free energy" (Friston, 2010), which is the energy left over after all essential functions are performed. In short, the brain is always open to offloading tasks because offloading preserves resources for the tasks that the brain deems most important.

Learning is also subject to the free energy hypothesis, as learning involves a mix of interrelated cognitive processes such as memory, problem solving, emotional regulation, and decision making. Researchers have applied the free energy hypothesis to cognitive functions associated with learning in the form of the minimal memory hypothesis. This hypothesis emerged from observations of memory tasks and describes how individuals choose to offload memory tasks, rather than memorize and store items in short-term or longer-term memory (Ballard et al., 1995). Acquiring new knowledge takes effort, as the brain captures sensations in the environment, compares these sensations to past ones, and consolidates these experiences into long-term memory. Learning may be an especially appealing task to offload because of the amount of free energy it consumes.

Research has revealed certain behavioral outcomes that result from COS that are associated with learning. For example, experiments have shown that individuals express greater confidence in their own abilities when they have relied on COS to learn (Hu et al., 2019). It is important to note that COS may increase confidence in what one has learned, even if the offloading has no positive impact on learning. Further, prior experience may guide decision-makers' use of COS as a substitute for learning. In experimental conditions, subjects chose to employ COS based on the belief that their past use of COS improved learning, even when there was no evidence to support that belief. In fact, this is a consistent finding: that COS is a preferred strategy because it eases difficult cognitive processes, but there is no evidence that COS improves accuracy (Dunn & Risko, 2015; Risko & Gilbert, 2016). Further, Risko et al. (2017) found that people are less likely to persist in solving a problem when they know a solution can be found elsewhere, suggesting that offloading may limit persistence when learning as well. In summary, individuals demonstrate a propensity to seek COS, which in turn limits persistence in learning, and they often believe that COS improves performance, even though there is no measurable improvement in learning.

Cognitive Offloading Strategies in Organizations

Like individuals, organizations often implement COS to offload learning. COS has benefits for organizations beyond efficiency, since it can standardize routines. By shifting routine activities to technology, COS frees the individual operator to focus on performing nonroutine and judgment-related tasks. COS has played an increasingly important role in aerospace design and has contributed to flight safety. The use of a checklist by cockpit crews to diagnose equipment failure is an illustration of COS. Checklists free up the need for pilots to store complex procedures in their long- or short-term memory. COS has become especially important as aircrafts have become more complex, as fly-by-wire or computer-controlled operations are now a primary design of commercial aircraft such as the Airbus 330 and the 737 Max. The need for COS, therefore, has become an essential element in training on and operating these complex aircrafts.

One of the first examples of COS in the aerospace industry occurred during the moon landing in Apollo 11. During the Apollo missions, computers were deployed, for the first time, to handle complex trajectory, speed, and weight calculations, leaving the pilot to focus on monitoring systems and visual information. Considered an important part of the successful moon landing, the computer was partially overridden in the final stages of the landing, as unexpected variance in the surface of the moon required the pilots to manually control the spacecraft in the final few hundred feet of descent towards the moon. The use of COS during Apollo 11 provided early insights into both the value and limitations of cognitive offloading. The computer was unable to recognize and recalculate the trajectory during descent due to anomalies in the surface of the moon that had not been accounted for in the programming. However, this was remedied because the pilots had knowledge of how to override the system and operate the landing module manually. One important lesson that can be learned from the Apollo 11 story is that even though the procedures relied heavily on COS, pilots were trained in the underlying technology and understood how to take manual control as it became necessary.

Cognitive Offloading and "Hidden" Gaps in Knowledge

As organizations adopt more COS, they become more likely to offload learning, including training, simulations, and other learning activities. As a result, organizational members, such as airplane pilots, learn and perform fewer tasks, which creates gaps in knowledge, and their subsequent understanding of systems and automation may become compromised. Thus, COS is of concern in extreme environments because it results in gaps in the procedural knowledge necessary to solve problems that might arise in crisis situations. Often associated with experts (Ericsson, 2018), procedural knowledge is the know-how associated with completing tasks or solving problems. Such knowledge is acquired over time, often through trial and error and with direct experience with the technology. In fact, experienced operators often cannot even explain how they reach decisions or solve tasks. Their ability to execute a task is often considered tacit, in the sense that it draws on years of experience in ways that cannot be easily codified or explained (Klein, 1999). Procedural knowledge is learned from participating in a variety of situations; therefore, having experience in a variety of situations is essential for developing procedural knowledge (Kolb, 2014). Procedural knowledge is also closely linked with intuition. Davenport and Prusak (2000) described the benefits of this kind of accumulated knowledge:

> Those with knowledge see known patterns in new situations and can respond appropriately. They don't have to build an answer from scratch every time. So, knowledge offers speed; it allows its possessors to deal with situations quickly, even some very complex ones… We arrive at an answer intuitively, without knowing how we got there. (p. 11)

Procedural knowledge, essential to quick and reliable decision making and action taking, is lost when organizations substitute COS for learning.

Another unintended consequence that results when COS substitutes for learning is of particular concern because situations that require learning are often stressful, and stress can lead to decrements in performance (Adi-Japha et al., 2008). Hannah et al. (2009) emphasized that nonstandard situations such as crisis, when occurring in an extreme environment, are associated with stress. Because operators, such as pilots, have not had experience solving problems under these stressful conditions, there is an increased likelihood that these decrements will arise. Therefore, COS may also intensify the problems associated with event-induced stress. Events that induce stress include time pressure, uncertainty over performance, and preperformance anxiety (Beilock & Carr, 2001). Beilock and Carr (2001) also outlined task characteristics that induce stress, such as task complexity (e.g., how many steps it takes to complete a task), the programmatic nature of the task (e.g., whether the task is routine or nonroutine), and if the task requires sensory-motor memory.

Cognitive Offloading through Technology and Transactive Memory

Knowledge gaps and incident-induced stress are not the only challenges that may be fueled by COS. COS may limit the ability of an organization to take advantage of collective action associated with performance during a crisis. Consider Wegner and Wegner's (1995) idea of transactive memory. Transactive memory proposes that memory is stored within our close social relationships and that complex tasks can, in part, be handled through coordination. Transactive memory has been described in disasters, crises, and aviation through Weick and Roberts's (1993) study of transactive memory in aircraft carriers. Importantly, Weick and Roberts (1993) pointed to transactive memory as a key factor in the success of aircraft carriers and as a key process in sustaining high-reliability organizations. Transactive memory is another form of resilience that has been well established in organizations and may be vulnerable to cognitive offloading. Thus, social knowledge, as well as knowledge of procedures, is another form of learning made vulnerable by use of COS. One example of how technology, stress, and decrements in learning interacted in an extreme environment was the KLM disaster at Tenerife (Weick, 1990). This disaster involved decrements in learning associated with stress; complex systems served as a general background, and degradation of teamwork contributed to the situation.

Aviation and Aerospace Disaster and the Study of Learning in Organizations

This section highlights two situations that resulted in disasters, the Air France Flight 447 (AF 447) and the Boeing 737 Max crashes. The incidents illustrate how COS may contribute to the breakdown of learning in aviation and aerospace. Aviation and aerospace incidents like AF 447 become particularly important because in disaster research, large samples are hard to come by and single incidents can have major consequences (March et al., 1991). Thus, close study of these events can enhance our understanding of the factors at the intersection of COS, learning, and human performance in extreme contexts.

Lessons from AF 447

An example of the decrements in learning that occurred in an aerospace context is the AF 447 disaster. About four hours into the flight, facing difficult weather patterns, the flight crew decided to ascend to maximum altitude to avoid the bad weather. The ascent seems to have led to a malfunction of a pitot tube, a sensor located on the exterior of the plane. The failure of the sensor led to a breakdown of the flight speed indicator, so that it provided inaccurate information in the cockpit, reporting a dramatic loss of air speed. The initial malfunction of the airspeed indicator, which reported misinformation to the cockpit, was misdiagnosed by the pilots, who applied the wrong maneuver to recover (Scott, 2010). This set off a series of automatic changes within the aircraft. An alarm sounded, distracting the pilots and, more importantly, the aircraft shifted from autopilot (normal law) to manual controls (alternate law).

While the pilots attempted to diagnose the problem, the less experienced of the two pilots in the cockpit took control of the aircraft. He eventually executed a recovery from inflight stall, commonly used during a landing.

The maneuver involves pointing the nose of the aircraft up and engaging the engines into near full throttle. The maneuver is often called the "togo" which stands for touch and go, because it is typically used to abort a failed landing. Seemingly unknown to the pilot, this maneuver does not work at high altitude. Once the senior pilots diagnosed the problem, it was too late and the airplane crashed (BEA, 2012).

The AF 447 incident provides an example of learning because the situation satisfies Gagne's (1962) eight criteria for learning in organizations. (1) *Gaining attention* (reception). The situation required responding to events. The cockpit crew focused on a specific event, the assumed loss of airspeed, and the resulting alarm demanded specific focus on the events at hand. (2) *Informing learners of the objective* (expectancy). The situation required identifying what the crew were trying to achieve. Diagnosis of why the stall warning was activated and taking proper action were expected outcomes of the alarm, stimulating recall of prior learning. The situation required the crew to call upon and recall prior skills, knowledge, or actions. (3) *Presenting the stimulus* (selective perception). The crew was required to identify what information was most important and, thus, where they should focus their attention. (4) *Providing learning guidance* (semantic encoding). The situation demanded an understanding from the pilots that they needed to put into place procedures, checklists, and prior experience in order to identify an appropriate solution. (5) *Eliciting performance* (responding). Successful response to the situation required an understanding of what outcomes or consequences would emerge as a result of the action. (6) *Providing feedback* (reinforcement). The situation required making adjustments so that the pilots could try different actions as part of the diagnosis and response. (7) *Assessing performance* (retrieval). The situation required the crew to assess the result of their actions and consider other viable alternatives. (8) *Enhancing retention and transfer* (generalization). The situation required the crew to transfer their knowledge from other situations to this situation and make appropriate judgments about what conditions needed to be adopted and applied.

The scenario also represented Kayes's (2015) notion of a learning situation, which is based on three factors of Wilensky's (1967) model of organizational intelligence. (1) *Lack of know-how*. The pilots misdiagnosed the situation and executed the wrong protocol because they were unaware of the proper procedure to use. (2) *Poor leadership and controls*. The cockpit crew consisted of three pilots. The captain had retreated to the back of the plane to sleep, leaving the leadership in the cockpit unclear. This may have resulted in the less experienced pilot taking the wrong action and the more experienced pilot failing to communicate intentions and actions. Another leadership concept is related to psychological safety, which describes how a team sets the context for another team member to bring up, express, and in some cases challenge current practices. Psychological safety is tied to leadership and controls because it is widely believed that leaders set the tone for the existence of psychological safety. (3) *Organizational level considerations such as policies, procedures, and design.* Some experts have discussed how the design of the cockpit may have led to confusion and how the design of high-tech planes can add to confusion in nonstandard situations (Wise, 2012).

Reconstruction of events such as that of AF 447 can offer insights as to how COS may have contributed to the disaster. Error (e.g., Reason, 1990) may explain, in part, the AF 447 disaster that emerged when pilots applied the wrong action in the face of a routine equipment failure. Learning also played a role, and learning theory may provide deeper insights into the pilots' misdiagnosis of the faulty air speed indicator, their lack of knowledge on how to solve the problem, and the role that a lack of experience operating under alternate operating conditions may have played. For example, experienced pilots can draw on more prior knowledge to respond to inflight anomalies than less experienced pilots. The events highlight both the importance of procedural knowledge (as a product of experience) and the added challenge of learning in the face of stress (Fischbacher-Smith & Elliott, 2006). Social and power dynamics were evident as well (Fraher, 2004). Further analysis might reveal the role of training and how safety training may or may not inform learning, as all pilots of the A330 had been informed of the problem with freezing pitot tubes through memos provided by Airbus. Yet, during the inflight disaster, pilots made no reference to knowledge of this problem.

Lessons from the Boeing 737 Max

COS may have contributed to other disasters, such as the development, production, and initial operation of the Boeing 737 Max. In this incident, pilots failed to understand an underlying technology and failed to respond to a routine operation. Aerospace manufacturer Boeing developed the 737 Max, in part, with the explicit goal to minimize the training (Robison & Johnsson, 2019) that would typically be required when introducing a new version of an aircraft into commercial use. Under most situations, introduction of a new aircraft model would have required pilot training, including training in a flight simulator. But with the 737 Max, Boeing promised airlines that the pilots who had been certified on earlier versions of the 737 aircraft would undergo limited training on the newest version of the 737—involving only an iPad rather than flight simulators.

Not only was training limited, but Boeing simulator and classroom training was replaced with specific automations that limited the need for pilot knowledge of specific flight characteristics of the aircraft. The automation would respond to certain specific flight situations that were unique to the 737 Max (Robison & Johnsson, 2019), eliminating the need for pilots to respond to certain common in-flight situations. This marked a clear example of COS, as training was offloaded to an algorithm deep inside the computer code that was responsible for operating most of these complex maneuvers. Pilots seemed to be convinced that training was not needed, which may have been the result of inexperienced pilots underestimating the risk of learning how to operate the new technology (Zohar & Erev, 2007). Captain Bhavye Suneja, pilot of the Boeing 737 Max involved in the fatal Lion Air Flight 610 accident, was reported to have discussed training with his mother before the crash: "'Mama, I'm going to fly the Max.' I said, 'How can you do that [when] you don't have [a] simulator session?' He said, 'We don't need to'" (McKirdy, 2018).

The Boeing 737 Max example brings into focus the vulnerabilities brought about by COS: when organizations substitute technology for learning, organizational operators, such as pilots, fail to learn the underlying mechanisms of technology. Even more important, in their attempt to offload learning to technology, organizations may be putting operators in situations where they lack basic knowledge, skills, and abilities to attend to anomalies that once were considered routine tasks. Loss-of-control accidents, like those that occurred in the AF 447 and in two 737 Max disasters, are too common. In private aviation, for example, they account for as many as 37 fatal accidents per year in Europe alone (European Union Aviation Safety Agency, 2021). A COS such as the introduction of new technologies that forgo the need for extensive training should give organizations pause, as it may increase decrements in learning.

Implications and Future Considerations

This section takes the decrements associated with COS as a given. Business problem redesign, worker shortages, increasing costs of training and salaries, easy substitution from cognition to technology, and other factors make increased use of COS inevitable in aerospace, aviation, and other organizations. COS is particularly tempting to industries like commercial aerospace, a field searching for means to reach economic viability.

Even under these and other pressures, there are steps organizations can take to limit the decrements brought about by COS. This section offers preliminary recommendations for theory, research, and practice. This will help the study and practice of human performance in extreme environments to move away from disaster and crisis and towards a stance of resilience (Powley, 2009). Considerations include applying criteria for when to use COS, creating experiential learning opportunities, and focusing on learning that is engaged, back-to-basics, and social.

Working Criteria for When to Substitute Cognitive Offloading for Learning

The first consideration is that adoption of COS may be based on the unrealistic assumption that technology can anticipate all possible problems and anomalies. This suggests boundary conditions for when COS is appropriate. Brynjolfsson and Mitchell (2017) outlined task characteristics that make machine learning difficult to adopt, which can serve as a starting point for a discussion of when to consider COS in organizations. Learning tasks or procedures that involve anomalies or a complex chain of events and that require updating and changing with each new event may be particularly difficult to substitute with COS. Tasks where there are only a few examples to model, tasks with no clear causal effects between inputs and outputs, tasks that require complex explanations and causal patterns, situations in which there is no tolerance for error, situations in which there are rapid changes in conditions, and tasks that lack clear goals are also areas for concern relating to the adoption of COS in place of learning. Because COS is "adopted not to optimize performance but to improve efficiency" (Risko et al., 2013, p. 550), when tasks and procedures hold these characteristics, COS as a substitute for learning strategies should be used cautiously.

Cognitive Offloading and Learning from Experience

Organizations should consider a broader range of learning activities, particularly experience-based activities, to address the limitations of COS. At the organizational level, a key consideration is determining the appropriateness of cognitive offloading. Should the knowledge that results from learning activity be stored in individual memory, or can it be stored in the external environment (e.g., checklists, computer code, algorithms, etc.), where it can be retrieved when needed?

Like checklists and manuals, retrieval of offloaded memory and procedures is often time consuming and inexact (Hu et al., 2019), which can be problematic when time is critical, such as in loss-of-control situations. Because individuals, and by extension organizations, tend towards offloading, even when there are not direct benefits to performance, consideration should be given as to how efficiently offloaded information and procedures can be retrieved (Hu et al., 2019). When COS is introduced, learning and related processes such as solving problems and exercising judgment should also be stressed as ways to support retrieving information, identifying underlying problems, and identifying solutions.

The operation of fly-by-wire systems, the technology underlying contemporary aircraft, seems like a good candidate for COS, because the technology limits anomalies and increases routine. Yet pilot decisions become complicated by the psychology associated with learning and flight. The intuitive feel of operating an aircraft may be difficult to quantify, and intuition is thought to play an important role in expert flying. A review of pilot training described it this way:

> For many years, aviators have considered flying to be a mixture of art and science. There are subjective as well as objective components of flying. Seat-of-the-pants flying is an excellent example. Pilots develop an implicit feel for the airplane that they have difficulty describing. This extends to teaching someone to fly and evaluating their performance. An instructor can read the instruments to judge performance, but their own senses and experience tell them more about the student's performance… These perceptions develop with experience. (Kaemph & Klinger, 1993, p. 39)

The *Airplane Flying Handbook* added: "Developing this 'feel' takes time and exposure in a particular airplane and only comes with dedicated practice at the various flight conditions so that a pilot's senses are trained by the sounds, vibrations, and forces produced by the airplane" (Federal Aviation Administration, 2020, pp. 3–4).

In addition, piloting a modern aircraft may be less physically demanding than it was during the days of manual controls, but factors like fatigue, stress, changing schedules and weather, cognitive and emotional overload, and lack of experience dealing with mechanical breakdowns are still factors that can lead to decrements in learning. Thus, learning from experience-based methods such as flight simulators and other training techniques is likely more valuable, in the long run, than COS.

Engaged Learning

Research has shown that the level of engagement associated with training can be predictive of the training's success. Burke et al. (2011) found that the more engaging the training in a safety context, the better the learning, which suggests that COS should be accompanied by highly engaging training and simulations. Highly engaged training more closely mirrors the experiences brought about by event-induced stress. Consider this description of the simulation training conducted during the NASA Apollo 11 moon landing program by former flight director Gene Kranz. The transcript is lightly edited.

> Training for the lunar mission was probably the most difficult time of my entire life. The training process, you have a training team led by an individual we called Sim Sup, simulation supervisor, and the Sim Sup's job is to come up with mission scenarios that are utterly realistic and will train every aspect of the crew and controllers and flight directors' knowledge. It'll test every aspect of the procedures and planning that we have put together. It'll test our facility operators. It'll test our ability to innovate strategies when things start to go bad… Training in Apollo was about as real—I mean, you would get the sweaty palms, you would have the—when the pressure was on in a training episode, it no longer was training, it was real, and the same emotions, the same feelings, the same energies, the same adrenaline would flow. (NASA Histories, 1999, pp. 20, 27)

The goal of engaged training is to improve operators' ability to deal with the stress response. Crum et al. (2013) found that mindset can be an important factor in dealing with the physical stress response. A physical stress response is a complicated mix of physical activities, involving the limbic and nervous systems, but when learners develop a "stress-is-enhancing mindset," they "accept and utilize stress toward achieving those enhanced outcomes" (Crum et al., 2013, p. 718). A stress-is-enhancing mindset may overlap with challenge stress, and they appear to predict several positive outcomes such as grade-point average.

Back-to-Basics Learning

Another consideration for learning is to consider basic understanding of organizational processes from the standpoint of organizational operations. For example, the U.S. Navy experienced an increase in the number of accidents that were attributed to, among other factors, lack of knowledge of basic navigation. Because officers and sailors lacked knowledge of particulars such as basic navigation techniques, they were unable to accurately detect and diagnose situations. In response, the U.S. Naval Academy instituted a new course that required students to learn basic navigation using a sextant to supplement their knowledge of electronic navigation (Prudente, 2017). The training emphasized the basic knowledge of navigation that underlies technology.

A similar back-to-basics approach to learning has been suggested in private aviation, but has not been implemented. The suggestion is that private pilots would be required to fly gliders, essentially planes without engines, which would teach the basic physics of flight through experience. Similar to the U.S. Navy, the Soaring program at the U.S. Air Force Academy introduces future pilots to the basics of flying through gliders.

Social Learning

Stress and power dynamics in the cockpit are two additional inputs that render algorithms inexpert in diagnosing and choosing responses. Fraher (2004) has shown the complex cultural and psychodynamic challenges associated with cockpit crews. Future research should build on this and develop a better understanding of how COS, including strategies that offload to other crew members (e.g., Wegner & Wegner, 1995), might help to mitigate some of the factors associated with offloading to technology alone.

International space station Mir had been plagued with system failures over its life, but the teamwork and cooperation across operators contributed to maintained operations. In fact, safety was such an issue that some U.S. officials questioned whether astronaut David Wolf should take his turn on the Russian Mir station. But when he arrived, he had prepared to work with his counterparts and had understood the potential vulnerabilities. Wolf explained:

> I had studied the systems for quite a long time. I had discussed all the failures with the people that experienced them and knew most about them. I had a good plan of action should such similar problems occur again or any other such problems that were anticipated, and I was extremely comfortable with the mission as a result of the training and the closeness to the issues. (NASA Histories, 1998, p. 2)
>
> The training was long and intense. We went north of the Arctic Circle, very serious survival training, both in water in the Black Sea and in more than forty degrees below zero outside for days. That's excellent for camaraderie and learning how people respond under stresses, not just to learn how to live when you land, if you happen to land in such a region, but it has other side benefits, perhaps more important, to learn how to get through the next hour, hour by hour, and stick to the task that's very difficult. [It is also important to recognize stress in other crewmembers and help them get through it.] [This is all] transferrable to a long-duration mission. (NASA Histories, 1998, p. 7)

Close training boosted his ability to learn how to deal with the anticipated as well as unanticipated failures. On Wolf's first spacewalk, he became stranded in space as the airlock mechanism failed to work on his reentry. After trying several alternatives, Wolf and the other three crew members, who were all Russian, decided to try a new entry point through a module used for sleeping. As they were communicating in Russian, Wolf's space helmet fogged up from the inside. He could only see through his helmet by spitting on the glass to clear the fog. Guided by the Russian crew, Wolf could only see a few inches, but noticed artifacts he had placed in the unanticipated reentry chamber. The close training with his Russian teammate created the conditions for them to communicate and improvise.

From the perspective of a technology–learning tradeoff, it was learning from experience, and even more important, learning to work with others that increased learning. Wolf learned how to communicate with those who knew the technologies as well as or better than he did. Thus, he learned to navigate the life-threatening challenge in a time-critical way under stressful conditions. Learning from his and others' experiences, not technological intervention, likely saved his life and mission (New York Public Radio, 2012).

Finally, as described earlier, COS may limit persistence because individuals have a mistaken belief that problems will be solved through technology; as such, there may be an overreliance on technological solutions. This belief not only informs the design and development of technology-based solutions, but also has implications for operators searching for solutions to problems in a crisis. Because of the mistaken belief that technology can be relied on to solve most or any problems, operators may believe that procedural knowledge is not necessary. This belief may be of particular concern in a crisis because technological solutions are not available and the problem-solving skills necessary to respond to the crisis have not been developed. Therefore, in addition to the considerations listed above, organizations should continue to challenge the often-unstated belief that technology itself will be the sole solution that prevents disaster.

Conclusion

COS is an important concept that deserves attention in the study of learning in organizations. Learning in extreme environments, like aviation and aerospace, provides an important context with which to study learning and COS. Organizations seek efficiency, and efficiency often comes at the expense of learning, which can have disastrous consequences. Organizations may be tempted to use COS as a substitute for learning, but this approach should be considered with care. COS is an inevitable part of working, learning, and performing in many extreme contexts and in more traditional organizations as well. As a supplement to or replacement for offloading, organizations should consider under what conditions they substitute learning for COS and implement learning practices that engage learners in situations that help operators develop a positive stress response, help them solve problems in the face of uncertainty, and highlight a procedural knowledge of operations.

References

Adi-Japha, E., Karni, A., Parnes, A., Loewenschuss, I., & Vakil, E. (2008). A shift in task routines during the learning of a motor skill: Group-averaged data may mask critical phases in the individuals' acquisition of skilled performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(6), 1544–1551. https://doi.org/10.1037/a0013217

Ballard, D. H., Hayhoe, M. M., & Pelz, J. B. (1995). Memory representations in natural tasks. *Journal of Cognitive Neuroscience*, *7*(1), 66–80. https://doi.org/10.1162/jocn.1995.7.1.66

BEA (Bureau d'Enquetes et d'Analyses pour la Securite de l'Aviation Civile). (2012). *On the accident on 1st June 2009 to the Airbus A330-203 registered F-GZCP operated by Air France flight AF 447 Rio de Janeiro-Paris. Final Report*. https://www.bea.aero/fileadmin/documents/docspa/2009/f-cp090601.en/pdf/f-cp090601.en.pdf.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General*, *130*(4), 701–725. https://doi.org/10.1037/0096-3445.130.4.701

Brynjolfsson, E., & Mitchell, T. (2017). What can machine learning do? Workforce implications. *Science*, *358*, 1530–1534. https://doi.org/10.1126/science.aap8062

Burke, M. J., Salvador, R. O., Smith-Crowe, K., Chan-Serafin, S., Smith, A., & Sonesh, S. (2011). The dread factor: How hazards and safety training influence learning and performance. *Journal of Applied Psychology*, *96*(1), 46–70. https://doi.org/10.1037/a0021838

Crum, A. J., Salovey, P., & Achor, S. (2013). Rethinking stress: The role of mindsets in determining the stress response. *Journal of Personality and Social Psychology*, *104*(4), 716–733. https://doi.org/10.1037/a0031201

Davenport, T. H., & Prusak, L. (2000). *Working knowledge: How organizations manage what they know*. Harvard Business School Press.

Dunn, T. L., & Risko, E. F. (2015). Toward a metacognitive account of cognitive offloading. *Cognitive Science*, *40*(5), 1080–1127. https://doi.org/10.1111/cogs.12273

Ericsson, A. (2018). *The Cambridge handbook of expertise and expert performance*. Cambridge University Press.

European Union Aviation Safety Agency. (2021). *Loss of control (LOC-I)*. https://www.easa.europa.eu/domains/general-aviation/flying-safely/loss-of-control

Federal Aviation Administration. (2020). *Airplane flying handbook* (FAA-H-8083-3B ed., Chapter 3). U.S. Department of Transportation. https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook/media/05_afh_ch3.pdf

Fischbacher-Smith, D., & Elliott, D. (2006). *Key readings in crisis management: Systems and structures for prevention and recovery*. Routledge.

Fraher, A. L. (2004). "Flying the friendly skies": Why US commercial airline pilots want to carry guns. *Human Relations*, *57*(5), 573–595. https://doi.org/10.1177/0018726704044310

Friston, K. (2010). The free-energy principle: A unified brain theory? *Nature Reviews Neuroscience*, *11*(2), 127–138. https://doi.org/10.1038/nrn2787

Gagne, R. M. (1962). Military training and principles of learning. *American Psychologist*, *17*(2), 83–91. https://doi.org/10.1037/h0048613

Hannah, S. T., Uhl-Bien, M., Avolio, B. J., & Cavarretta, F. L. (2009). A framework for examining leadership in extreme contexts. *Leadership Quarterly*, *20*(6), 897–919. https://doi.org/10.1016/j.leaqua.2009.09.006

Hu, X., Luo, L., & Fleming, S. M. (2019). A role for metamemory in cognitive offloading. *Cognition*, *193*, 104012. https://doi.org/10.1016/j.cognition.2019.104012

Kaemph, G. L., & Klinger, D. W. (1993). *Integrated measurement of crew resource management and technical flying skills*. Federal Aviation Administration. https://apps.dtic.mil/dtic/tr/fulltext/u2/a270512.pdf

Kayes, D. C. (2015). *Organizational resilience: How learning sustains organizations in crisis, disaster, and breakdown*. Oxford University Press.

Klein, G. (1999). *Sources of power*. MIT Press.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development* (2nd ed.). Prentice-Hall.

March, J. G., Sproull, L. S., & Tamuz, M. (1991). Learning from samples of one or fewer. *Organization Science*, *2*(1), 1–13. https://doi.org/10.1287/orsc.2.1.1

McKirdy, E. (2018, November 28). *Lion Air crash: Pilot fought automatic safety system before plane plunged*. CNN. https://www.cnn.com/2018/11/28/asia/lion-air-preliminary-report-intl/index.htm

NASA Histories. (1998). *Interview with David Wolf*. Interviewers: Rebecca Wright, Paul Rollins, Mark Davison [ISS Phase 1 History Project]. https://history.nasa.gov/SP-4225/oral-histories/wolf.pdf

NASA Histories. (1999). *Eugene F. Kranz interviewed by Rebecca Wright, Houston, Texas* [Oral History 2 Transcript]. https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/KranzEF/EFK_1-8-99.pdf

New York Public Radio. (2012). *Radiolab*. *Darkside of the Earth*. https://www.wnycstudios.org/podcasts/radiolab/articles/242184-dark-side-earth

Powley, E. H. (2009). Reclaiming resilience and safety: Resilience activation in the critical period of crisis. *Human Relations*, *62*(9), 1289–1326. https://doi.org/10.1177/0018726709334881

Prudente, T. (2017, August 8). Naval Academy reinstates celestial navigation. *Military Times*. https://www.militarytimes.com/news/your-military/2015/11/01/naval-academy-reinstates-celestial-navigation/

Reason, J. (1990). *Human error*. Cambridge University Press.

Risko, E. F., & Gilbert, S. J. (2016). Cognitive offloading. *Trends in Cognitive Sciences*, *20*(9), 676–688. https://doi.org/10.1016/j.tics.2016.07.002

Risko, E. F., Huh, M., Mclean, D., & Ferguson, A. M. (2017). On the prospect of knowing: Providing solutions can reduce persistence. *Journal of Experimental Psychology: General*, *146*(12), 1677–1693. https://doi.org/10.1037/xge0000334

Risko, E. F., Medimorec, S., Chisholm, J., & Kingstone, A. (2013). Rotating with rotated text: A natural behavior approach to investigating cognitive offloading. *Cognitive Science*, *38*(3), 537–564. https://doi.org/10.1111/cogs.12087

Robison, P., & Johnsson, J. (2018, December 20). Boeing's push to make training profitable may have left 737 Max pilots unprepared. *Bloomberg Businessweek*. https://www.bloomberg.com/news/articles/2019-12-20/boeing-s-profit-push-may-have-left-737-max-pilots-unprepared

Scott, W. R. (Director). (2010). *Crash of Flight 447*. Nova.

Wegner, T. G., & Wegner, D. M. (1995). Transactive memory. In A. S. R. Manstead & M. Hewstone (Eds.), *The Blackwell encyclopedia of social psychology* (pp. 654–656). Blackwell.

Weick, K. E. (1990). The vulnerable system: An analysis of the Tenerife air disaster. *Journal of Management*, *16*(3), 571–593. https://doi.org/10.1177/014920639001600304

Weick, K. E., & Roberts, K. H. (1993) Collective mind in organizations: Heedful interrelating on flight decks. *Administrative Science Quarterly*, *38*(3), 357–381. https://doi.org/10.2307/2393372

Wilensky, H. L. (1967). *Organizational intelligence*. Basic Books.

Wise, J. (2012, July 9). Air France 447 and the limits of aviation safety. *Popular Mechanics*. https://www.popularmechanics.com/flight/a7813/air-france-447-and-the-limits-of-aviation-safety-10487501/

Zohar, D., & Erev, I. (2007). On the difficulty of promoting workers' safety behaviour: Overcoming the underweighting of routine risks. *International Journal of Risk Assessment and Management*, *7*(2), 122–136. https://doi.org/10.1504/ijram.2007.011726